Defense Advanced Research Projects Agency

NETEX Program

Networking in Extreme Environments

Ultra Wideband Electromagnetic Interference Test Report

AN/ASN-163 and AN/PSN-11 GPS Receivers

Rockwell Collins GPS Test Report

July 10, 2003

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The Defense Advanced Research Projects Agency (DARPA)
Networking in Extreme Environments (NETEX) Program

UWB EMI TEST REPORT FOR THE AN/ASN-163 AND AN/PSN-11 GPS RECEIVERS

EXECUTIVE SUMMARY

The goal of the Networking in Extreme Environments (NETEX) Program is to create a wireless networking technology that enables robust connectivity in harsh environments and support its integration into new and emerging sensor and Navigation receivers. The NETEX program is focused on the development of an improved physical layer for networked Navigations based on a family of new ultra-wideband UWB devices. UWB devices have the potential to perform a number of useful military Navigation and sensing functions that make them very appealing for warfighter applications.

This report is one of a series of NETEX sponsored electromagnetic interference (EMI) test reports that detail the effects of interference from UWB transmissions on legacy military receivers. The purpose of this report is to document the results of EMI testing performed on the AN/ASN-163 and AN/PSN-11 GPS Navigation Receivers using an UWB signal generator as the potential interfering source.

The AN/ASN-163 GPS Navigation Receiver is a five channel Miniaturized Airborne GPS Receiver. The AN/PSN-11 GPS Navigation Receiver is a five channel handheld GPS receiver.

The report provides detailed descriptions of the UWB signal source and AN/ASN-163 and AN/PSN-11 operating modes, identifies the test methodology and test procedures and presents the results of the test events. The intent of these tests was to determine the relative susceptibility with respect to a standard RF interference signal of the AN/ASN-163 and AN/PSN-11 receivers for several of the primary operating modes of the receivers. Accordingly, a set of thirteen test waveforms were designed and injected into the receivers in order to be able to measure the interference effects. The results of the tests are presented in relative susceptibility plots and summarized in a data table.

The results of the tests demonstrated that for most of the thirteen UWB test waveforms and test types, the AN/ASN-163 and the AN/PSN-11 GPS receivers were less susceptible to the UWB waveforms than to an equivalent white noise or CW interferer. This means that for most of the waveforms, UWB interference caused an equivalent EMI effect in the receivers at higher power levels than for the white noise or CW levels. Only in a few cases was relatively susceptibility of the UWB waveform significantly worse than the standard RFI.

The EMI impact was found to vary depending on the characteristics of the test waveform. In general, the impact of UWB interference on signal strength was more benign than for the pseudorange performance. Pseudorange performance exhibited much more varied performance depending strongly on the waveform type, as alluded to in the previous paragraph. A possible explanation of this behavior is that the manner in which the UWB interference impacts the C/N_0 detector in the receivers is significantly different than UWB interference on the PR measurement generation processing.

The data presented in this report is unclassified because it does not reveal vulnerabilities of the GPS receivers tested, such as loss of lock thresholds. The relative susceptibility measures are computed from unclassified performance data collected while the receiver was still in lock.

SECTION 1 INTRODUCTION

1.1 BACKGROUND

The Defense Advanced Research Projects Agency (DARPA) is the central research and development organization for the Department of Defense (DoD). DARPA manages and directs basic and applied research and development projects for DoD, pursuing technology where risk and payoff are usually both very high. High payoff results may provide dramatic advances in Navigation support to our ability to wage modern warfare. The DARPA Networking in Extreme Environments (NETEX) program seeks to create a wireless networking technology for the military user that enables robust connectivity in a wide spectrum of environments and support its integration into new and emerging sensor and Navigation receivers.

Recent advances in microcircuits and other technologies have resulted in the development of pulsed radar and Navigations receivers with very narrow pulse widths and very wide bandwidths. These ultra wideband (UWB) devices can perform a number of useful telecommunications and navigation functions that make them very appealing for both the commercial and government applications. These receivers have very wide information bandwidths, are capable of accurately locating nearby objects, and can use processing technology with UWB pulses to "see through objects" and communicate using multiple propagation paths.

The NETEX program will develop an improved physical layer for networked Navigations based on a family of new UWB devices. These devices will enable reliable and efficient operations in harsh environments by exploiting the unique properties of UWB systems that allow them to work in a dense multi-path environment and to function as both sensors and Navigations devices. The program will adapt new and emerging ad-hoc routing protocols and multiple access schemes to take advantage of the unique properties of UWB to communicate in harsh environments, to very accurately resolve range, and to act as a radar based sensor.

The NETEX program will be executed in three phases comprising four tasks. The goal of Phase 1 (Task (1)) is to obtain a thorough understanding of how UWB systems interact with other spectrum users and how they could be implemented in a manner that makes best use of their unique capabilities. Phase 1 consists of a combination of actual UWB electromagnetic interference (EMI) tests on selected military systems and a program of UWB system modeling and simulation. The results of Phase 1 will be the identification of the military UWB system design space and a set of tools for the prediction of UWB interaction with other systems. The results will be used to direct the development of operating UWB systems during Phases 2 and 3 of the program.

This report is one of a series of NETEX Phase 1 EMI test reports addressing the results of UWB EMI testing on a selected set of military receivers. The information contained in this report with the results of NETEX sponsored UWB EMI testing on other military

systems will contribute to the goals of the NETEX program. Specifically, the results of these tests will be used to gain a thorough understanding of the effects of various modes of UWB system operation on military receivers. The results will provide the information necessary to evaluate the potential for UWB signals to interfere with the AN/ASN-163 and AN/PSN-11 and to understand how UWB systems could be implemented to make use of their unique capabilities without causing EMI.

1.2 OBJECTIVE

The objective of this test was to determine the EMI relative susceptibility of the AN/ASN-163 and AN/PSN-11 Navigation Receivers to conducted ultra-wideband (UWB) signals that were injected into the receiver antenna port.

1.3 APPROACH

In order to accomplish the EMI test objective, the DARPA NETEX program developed a Test Master Plan and specific test plans for each of the GPS receivers. UWB signal generators developed and supplied by Multispectral Solutions, Inc. (MSSI) were used for conducting the tests. A description and characterization of the UWB devices is contained in Section 2.3.

The tests were performed at the Rockwell Collins facility by personnel familiar with EMI test equipment and EMI test procedures and techniques.

The parameters that were measured include:

- Baseline performance thresholds of the AN/ASN-163 (MAGR) for P-code pseudorange (PR) standard deviation, C/A-code PR std. dev. and position/signal strength deviation and
- Baseline performance thresholds of the AN/PSN-11 (PLGR) for P-code pseudorange (PR) standard deviation and position/signal strength deviation and
- Relative susceptibility of the AN/ASN-163 and AN/PSN-11 receiver (in the presence of added white noise and/or CW in-band interference) to the UWB interfering signals.

The tests were performed for the AN/ASN-163 and the AN/PSN-11 GPS receivers with 13 UWB test waveforms, although for some of the tests, the results for all 13 waveforms were not able to be determined either due to equipment or schedule constraints. The test waveforms are described in Section 2.3.

SECTION 2 THE AN/ASN-163 AND AN/PSN-11 GPS RECEIVERS, UWB SIGNAL GENERATOR AND UWB TEST WAVEFORMS

2.1 AN/ASN-163 AND AN/PSN-11 GPS RECEIVERS

The AN/ASN-163 is the Miniaturized Airborne GPS Receiver (MAGR). The MAGR is a 5-channel P-Code L1/L2 GPS receiver designed for airborne platform navigation. The tested unit is the MAGR R-2512A/U CPN 822-0208-002 SN 215 with Link 10 software load.

The AN/ASN-163 MAGR has operational frequencies of 1575.42 MHz (L1) and 1227.6 MHz (L2). The standard responses are 3-D position and velocity. The GPS signal modulation is pseudo-random BPSK at 10.23 MHz (P-code), 1.023 (C/A-code) MHz rates. The GPS signal also contains a 50 bps BPSK satellite ephemeris data overlay. The MAGR IF Bandwidth is 25 MHz (nominal). The MAGR has sensitivity sufficient to acquire and track GPS SPS and PPS signals at -130 to -136 dBm.

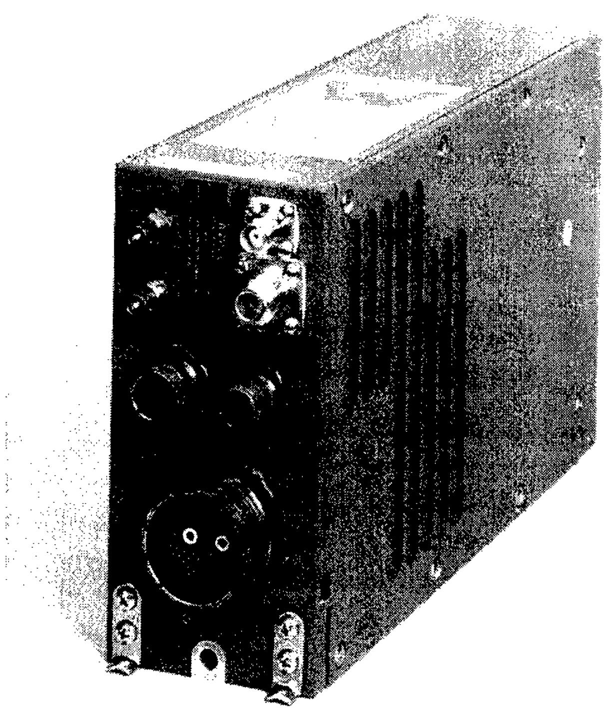


Figure 1. AN/ASN-163 MAGR GPS Receiver

The AN/PSN-11 is the Precision Lightweight GPS Receiver (PLGR). The PLGR is a 5-channel P-Code L1 GPS portable handheld/vehicular receiver designed for land warrior navigation. The test unit is the PLGR HNV-500C CPN 822-0077-103 Rev H SN 1711 with 613-9868-078 software load.

The AN/PSN-11 PLGR has an operational center frequency of 1575.42 MHz (L1). The standard responses are 3-D position and velocity. The GPS signal modulation is pseudo-random BPSK at 10.23 MHz (P-code), 1.023 MHz (C/A-code) rates. The GPS signal also contains a 50 bps BPSK satellite ephemeris data overlay. The PLGR IF Bandwidth is 25 MHz (nominal). The PLGR has sensitivity sufficient to acquire and track GPS SPS and PPS signals at -130 to -136 dBm.

Figure 2. AN/PSN-11 PLGR GPS Receiver

2.2 UWB SIGNAL GENERATOR

The Ultra Wideband (UWB) signal generators utilized for the NETEX Program were developed and supplied by Multispectral Solutions, Inc. (MSSI). The BFP1000 UWB Signal Emulator device produces a triggered pulse which is nominally 25 psec wide. Pulse spacing is a minimum of 5 nsec. A typical pulse is shown in Figure 3~~Figure 3~~.

Through the use of an external arbitrary waveform generator (AWG, ARB), the UWB signal generators can produce an extensive variation of waveforms including regular pulse repetition rates (PRR), jittered PRR, on/off keying, and Pulse Position Modulation (PPM).

The UWB generator default double exponential output pulse shape was used. The pulse can be generated with its leading edge as positive going or negative going by use of the external positive and negative trigger inputs. Doublet pulses are created using a pair of synchronized AWG produced waveforms for the external positive and negative UWB pulse triggers. All other AWG generated pulse triggering used the UWB external positive trigger input only.

The UWB Signal Generator was used in the default full bandwidth output (0 – 8 GHz). Internal band pass limiting filters were available, but not used for this testing.

In addition to the UWB generators, the program obtained a set of reference antennas for the piecewise continuous sub-bands of the UWB generated signal. These were used during the antenna study.

For the purposes of the AN/ASN-163 and AN/PSN-11 tests, the baseband, unfiltered, positive double exponential pulse and the double exponential pulse synchronously triggered as a doublet were used. All trigger waveforms were supplied externally by an AWG.

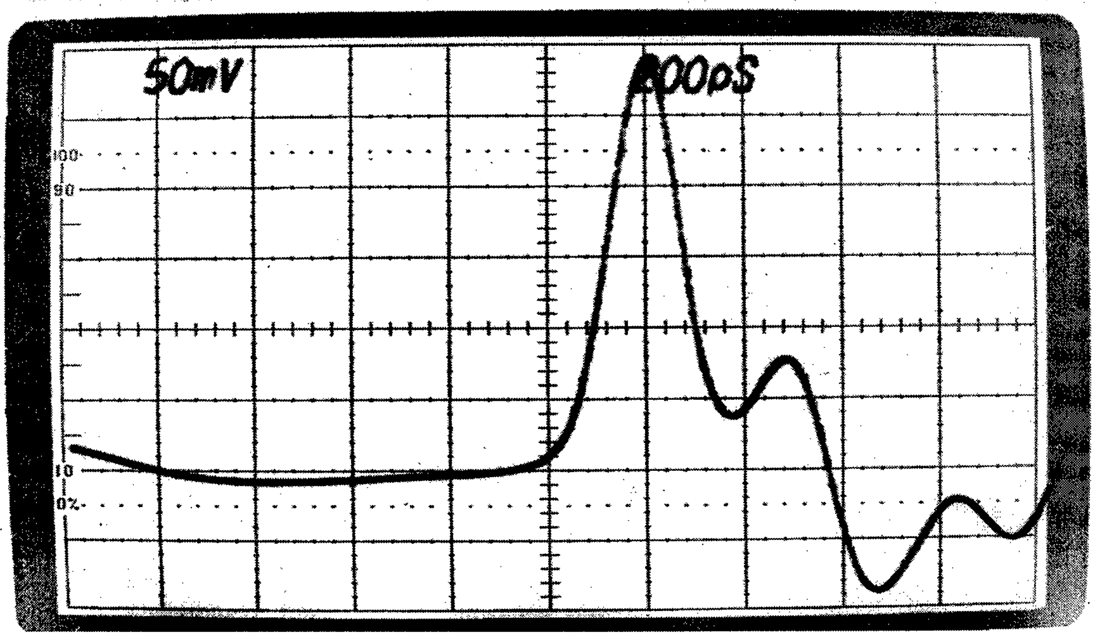


Figure 3. Typical Positive Triggered MSSI UWB Generator RF Output Pulse, 20 picoseconds per horizontal division

2.3 TEST WAVEFORMS

The UWB waveforms that were used for the GPS tests are as follows:

- 1.0 MHz uniform Pulse Repetition Frequency (PRF)
- 1.994 MHz uniform PRF
- 10.0 MHz uniform PRF
- 19.94 MHz uniform PRF, 100% duty cycle
- 20.0 MHz uniform PRF

- 15.91 MHz nominal PRF, 2 position PPM dithered
- 15.94 MHz nominal PRF, 2 position PPM dithered
- 1.994 MHz nominal PRF, 10 position PPM dithered
- 2.0 MHz nominal PRF, 10 position PPM dithered

- Gold code modulated doublet, 57.08 kHz PRF, continuous (i.e., 100% duty cycle)
- On/Off Keying (OOK) custom waveform, fixed 23 bit preamble followed by pseudorandom data stream of 4096 bits at 200 MHz

- 19.94 MHz uniform PRF, 50% duty cycle
- Gold code modulated doublet, 57.08 kHz PRF, 40% duty cycle (22.83 kHz effective PRF)

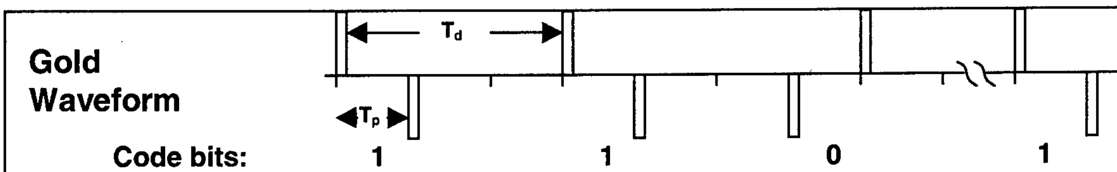
The table below illustrates the relationship between the GPS UWB test waveform designations and the NETEX master test plan waveform descriptions.

Table 1 UWB RFI Waveform List for GPS Testing

Waveform	Netex Master Plan	Collins GPS Plan	Comments
TW1	Max Unif. PRF – line in Rx BW	19.94 MHz Unif. PRF	$79 \times PRF = F_{L1} - 0.16$ MHz
--	--	20.00 MHz Unif. PRF	$79 \times PRF = F_{L1} + 4.58$ MHz
--	--	19.94 MHz PRF, 50% DF Burst, 500 Hz rate	$79 \times PRF = F_{L1} - 0.16$ MHz, fine line spacing – 500 Hz
TW2	Max PRF+ 25%-100% IF bw dither	15.91 MHz nom PRF 2-pos dither (252K bit)	$99 \times PRF = F_{L1} - 0.33$ MHz
TW3	Ave. PRF=IF bw, 25-100% dither	15.94 MHz nom PRF 2-pos dither (252K bit)	$99 \times PRF = F_{L1} + 2.64$ MHz
--	--	1.994 MHz nom PRF, 10-pos dither (250K bit)	$790 \times PRF = F_{L1} - 0.16$ MHz
--	--	2.000 MHz nom PRF, 10-pos dither (250K bit)	$790 \times PRF = F_{L1} + 4.58$ MHz
--	--	10.0 MHz Unif. PRF	$0.5 \times$ IF bw
TW4	Ave. PRF=IF bw+mod	N/A	
TW5	Unif. PRF=0.1× IF bw	1.994 MHz Unif. PRF	$790 \times PRF = F_{L1} - 0.16$ MHz
TW6	Unif. PRF=10× IF bw	N/A	TW9 has 58.4 MHz PRF
TW7	Unif. PRF=0.01×IF bw	1.0 MHz Unif. PRF	$0.05 \times$ IF bw
TW8	OOK data pattern	On/Off Keying	Header + random OOK data
TW9	"Gold" doublet 100%	"Gold" doublet 100%	1024 Bit BPSK mod,
--	--	"Gold" doublet 40%	17.5 us burst, 23 kHz PRF

The Uniform UWB waveforms are equally spaced, positive going RF pulses at the primary repetition frequency (PRF). The 50% reduced duty cycle uniform PRF waveform presents uniform positive going pulses for 20 msecs followed by 20 msecs with no pulses. The dithered UWB waveforms have a fundamental pulse repetition frequency, with the RF pulse being offset into either one of either two or ten time slots adjacent to the fundamental time placement. The offset determination is pseudorandom for all of the dithered waveforms. For on/off keying, the UWB pulse is either at the designated time slot as define by the fundamental frequency or it is not there.

The Gold Code UWB waveform is a doublet pulse, where the UWB pulses are transmitted as a pair consisting of one positive and one negative pulse. The typical Gold code sequence and the pulse separation and timing used for this UWB waveform is shown in the figure below.



Code = 1023 bits - maximal length Tp = 5.708 ns Td = 17.123 ns
Doublet PRF = 58.4 MHz

Spectrum envelope has nulls at multiples of 175.2 MHz (= 1/Tp)
e.g. 350.4,...1051.2, 1226.4, ...1576.8 MHz

Generated trigger patterns with complementary sequences on dual channel Tek AWG-2021 with internal 175.2 MHz clock

Figure 44. Gold Code UWB Waveform

Plots of the RF spectral output in the region of interest (GPS L1 1575.42 MHz) for each of the UWB waveforms is included in Appendix A.

SECTION 3 EMI TESTS SUMMARY

3.1 RECEIVER BASELINE PERFORMANCE

In order to measure and determine the relative susceptibility of the receiver for a particular operating mode it was first necessary to establish the baseline receiver performance. This involves defining the standard RF interference (RFI) for the test as well as the standard RFI level to be used. The standard RFI level results in a particular performance threshold, which is in turn used as the measure of impact of the UWB interference with respect to the standard RFI.

For the MAGR, three different operation modes, which correspond to three different test types, were investigated in this effort. These are the P-code PR std. dev. performance, C/A-code PR std. dev. performance and steady-state position/signal strength deviation performance. For the P-code and C/A-code PR tests, the standard RFI was wideband white noise in the receiver passband. This choice was based on following the UWB interference testing methodology developed under FAA funding on civil aviation GPS receivers. For the steady-state position/signal strength test the standard RFI was narrowband tone (CW) interference. However, for this test wideband noise was also injected in the receiver in order to establish the proper signal to noise conditions for the test. This third test was based on the legacy susceptibility test used for MAGR qualification testing.

For the PLGR, two different operation modes, which correspond to two different test types, were investigated in this effort. These are the P-code PR std. dev. performance and steady-state position/signal strength deviation performance. For the P-code PR test, the standard RFI was wideband white noise in the receiver passband. For the steady-state position/signal strength test the standard RFI was narrowband tone (CW) interference. However, for this test wideband noise was also injected in the receiver in order to establish the proper signal to noise conditions for the test. The two PLGR tests were designed to be similar to the MAGR tests for ease of comparison and since there were no legacy PLGR susceptibility tests that could be adapted for our testing purposes.

For the three MAGR and two PLGR test types, Table 2~~Table 2~~ gives the resulting performance threshold values. The levels of standard RFI required to achieve these threshold values were determined experimentally for each test as defined in the detailed test plans for the respective receivers. For the PR std. dev. tests, the standard RFI levels were chosen in order to maintain steady-state tracking in a "worst case" interference environment. This is described in greater detail in Section 4. For the position/signal strength tests the threshold values were taken from the legacy MAGR susceptibility test.

Table 2. GPS Receiver Threshold Values

GPS Receiver and Test Type	Performance Threshold Value	Note
AN/ASN-163 MAGR P-code PR Test	0.4 meters	Unsmoothed PR computed over 5 min interval
AN/ASN-163 MAGR C/A-code PR Test	2.8 meters	Unsmoothed PR computed over 5 min interval
AN/ASN-163 MAGR Position/Signal Strength Test	C/No=28 dB-Hz	+/- 2 dB from 30 dB-Hz
AN/PSN-11 PLGR P-code PR Test	0.4 meters	Unsmoothed PR computed over 5 min interval
AN/PSN-11 PLGR Position/Signal Strength Test	C/No=28 dB-Hz	+/- 2 dB from 30 dB-Hz

3.2 UWB INTERFERENCE TESTS

Given the baseline performance of the receivers to the standard RFI for the various test types, the relative susceptibility to UWB interference for each of the 13 waveforms was then determined. As noted in Section 1, for some of the five test types, results for all 13 waveforms were not able to be determined. Hence for each of the five test types, up to 13 relative susceptibility curves were computed.

In order to compute relative susceptibility for a particular UWB waveform, the standard RFI power level injected into the receiver was lowered by a certain amount and UWB power was added until the performance threshold for the particular test type was achieved. The amount of UWB power needed to achieve the performance threshold compared to the amount of standard RFI power removed indicates the relative susceptibility of the receiver for that test for that particular waveform. More specific detail about the testing methodology is given in Section 4.

The three PR tests (two for the MAGR and one for the PLGR) were "three signal" tests in that the tests were conducted with three signals being simultaneously injected in the receiver. These signals were the GPS signal (which, of course, consisted of multiple satellite signals), the standard RFI (which was broadband, white noise for the PR tests), and the UWB waveform (each of the 13 UWB waveforms was tested individually). The Position/Signal Strength tests were "four signal" tests. This is because white noise was also injected into the receiver along with the standard RFI CW tone, in addition to the GPS signals and UWB waveform. However, for these tests the white noise signal was held constant, because it was not considered part of the standard RFI. It was only included to provide the proper C/N_0 baseline level.

All testing was performed at GPS L1.

3.3 SUMMARY OF TEST RESULTS

A summary of the test results for the five test types (three from MAGR and two for PLGR) are given in Figure 5~~Figure 5~~ to Figure 13~~Figure 13~~ and in Table 3~~Table 3~~. The figures graphically show the relative susceptibility results for the waveforms tested. Note that for the first four test types there are two figures each, e.g., Figure 5~~Figure 5~~ and Figure 6~~Figure 6~~ are the first pair for the MAGR P-code PR test type results. The first figure of each pair is shown with a ten times expanded y-axis to show the waveforms that had much less impact than the equivalent amount of standard RFI. The second figure of each pair has equal scales for the x and y axes in order to more clearly illustrate those waveforms whose relative susceptibility performance was clustered more closely near the unity slope line, which indicates equivalent impact as the standard RFI.

The table provides a qualitative summary of the relative susceptibility performance of the 13 waveforms for each of the five test types for rapid side by side comparison. Note that desirable UWB waveforms are those that have less impact than the standard RFI and this is indicated in the table with a minus or double minus sign.

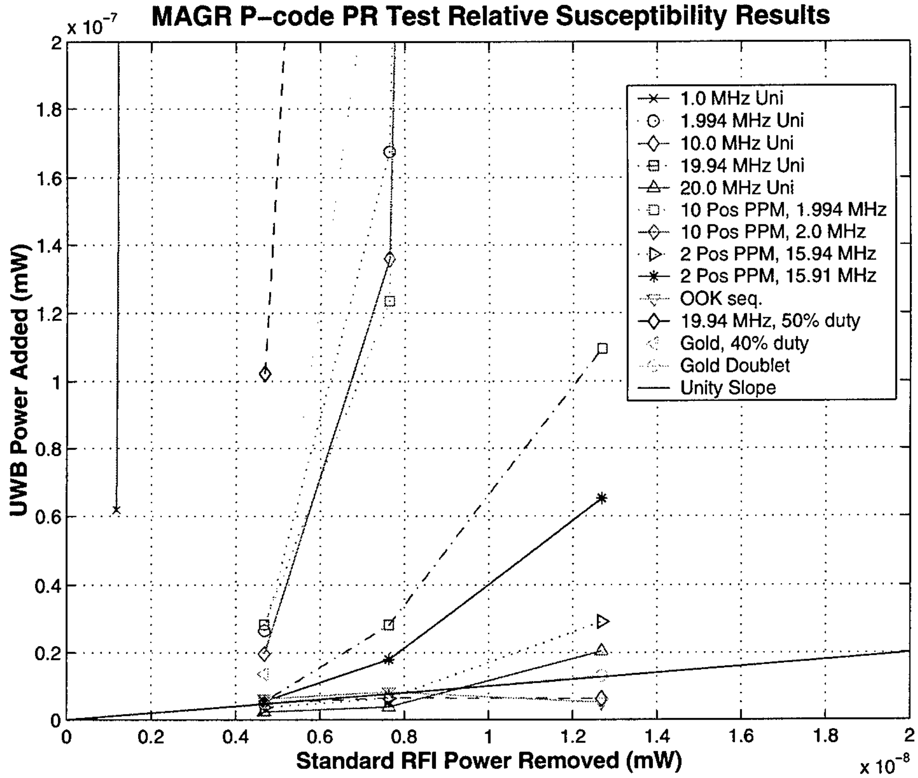


Figure 55. Plot of MAGR P-code PR test results, y axis ten times x axis.

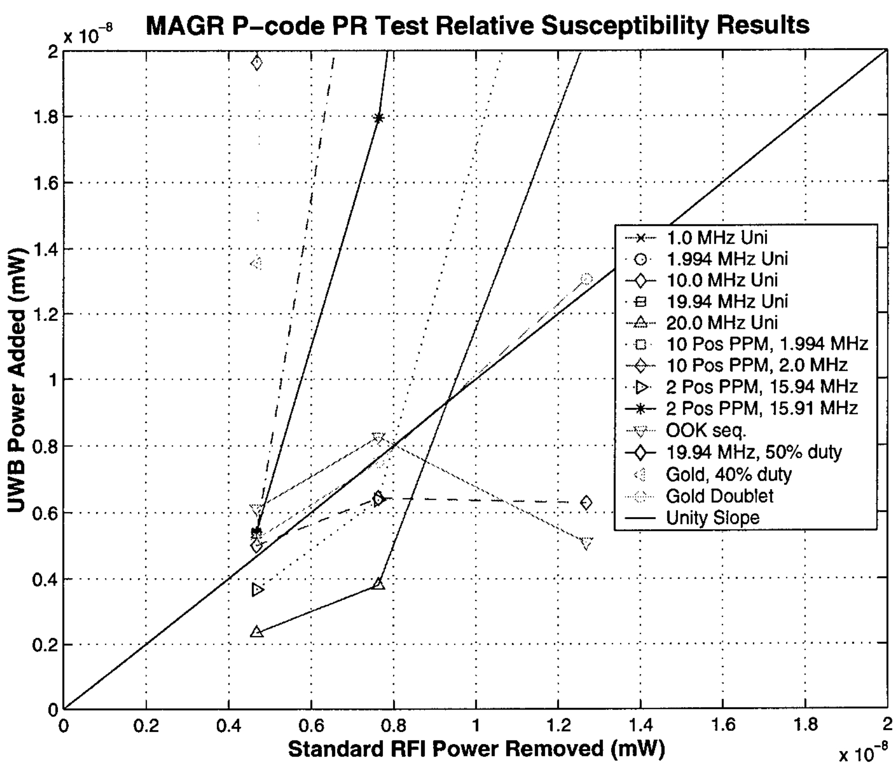


Figure 6. Plot of MAGR P-code PR test results, x axis and y axis equal.

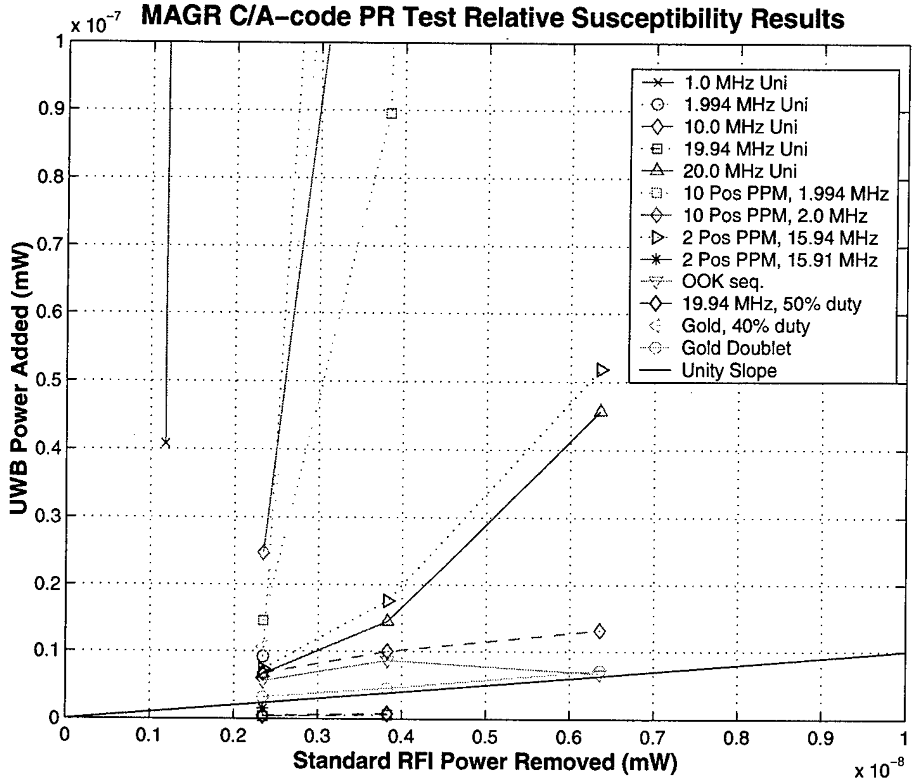


Figure 77. Plot of MAGR C/A-code PR test results, y axis ten times x axis.

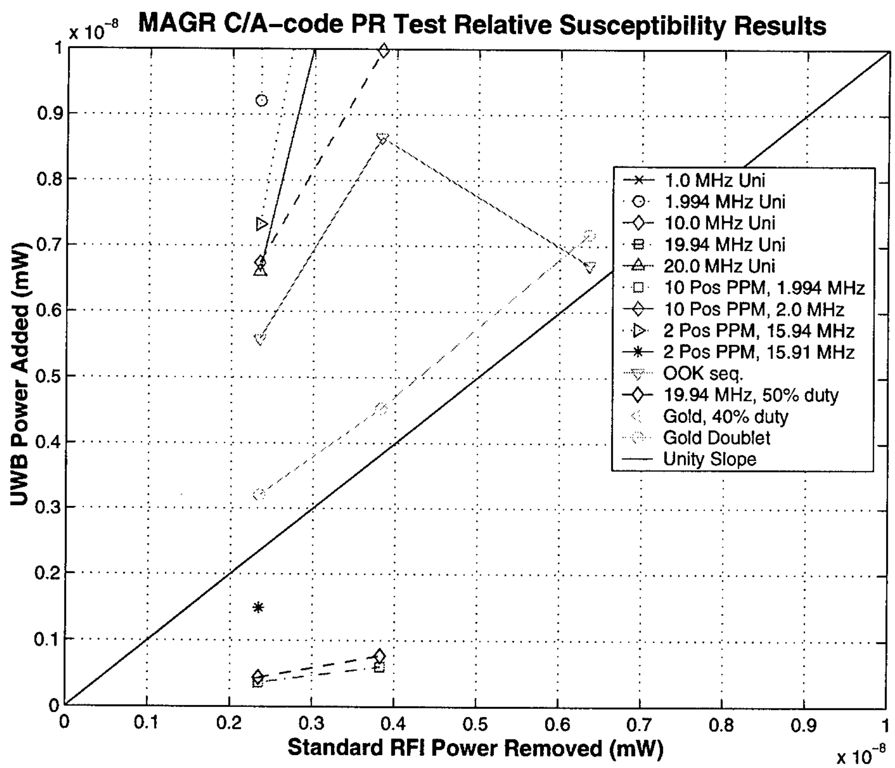


Figure 88. Plot of MAGR C/A-code PR test results, x axis and y axis equal.

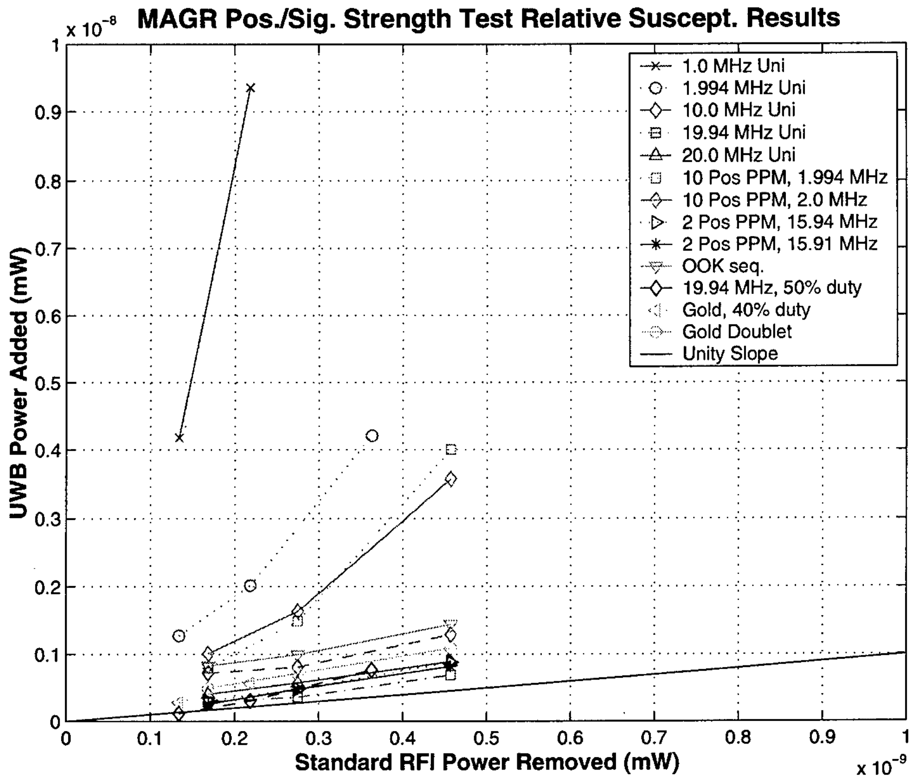


Figure 99. Plot of MAGR Position/Signal Strength test results, y axis ten times x axis.

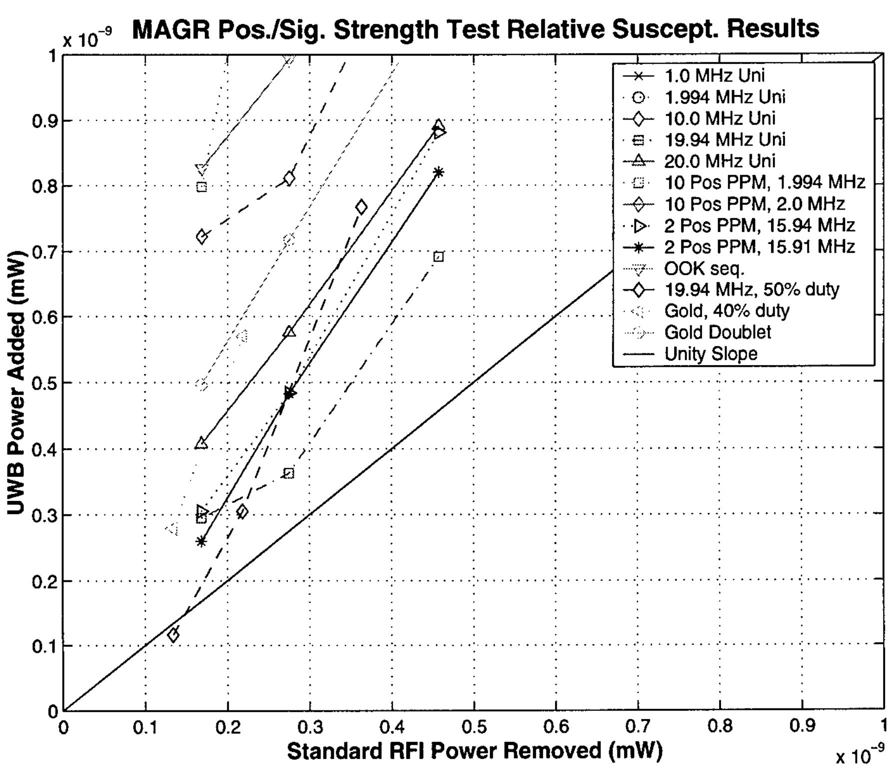


Figure 10~~10~~. Plot of MAGR Pos./Signal Strength test results, x axis and y axis equal.

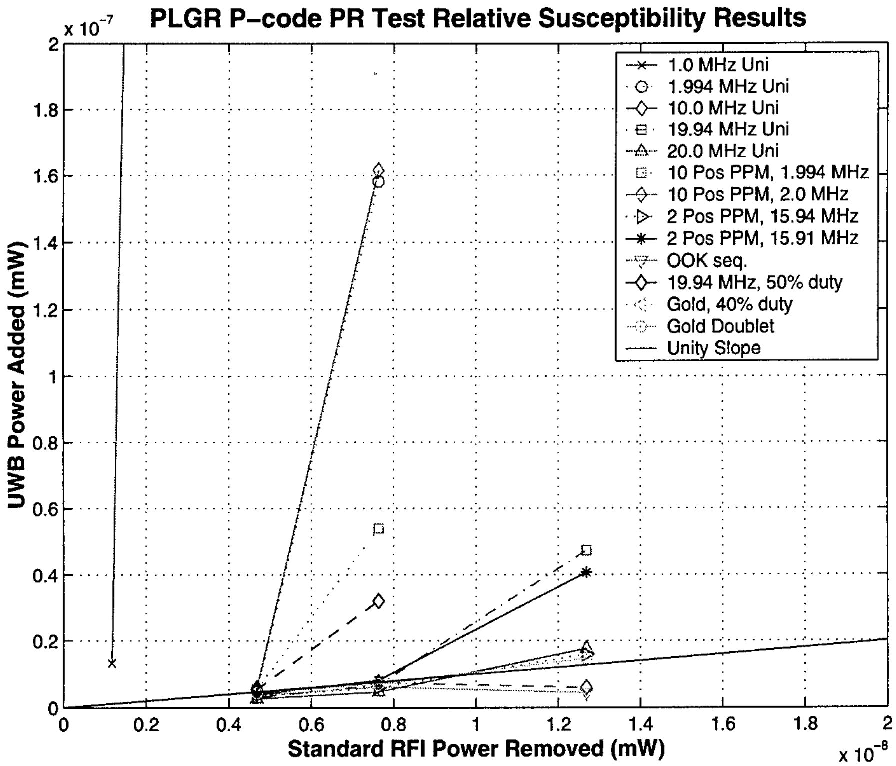


Figure 11~~11~~. Plot of PLGR P-code PR test results, y axis ten times x axis.

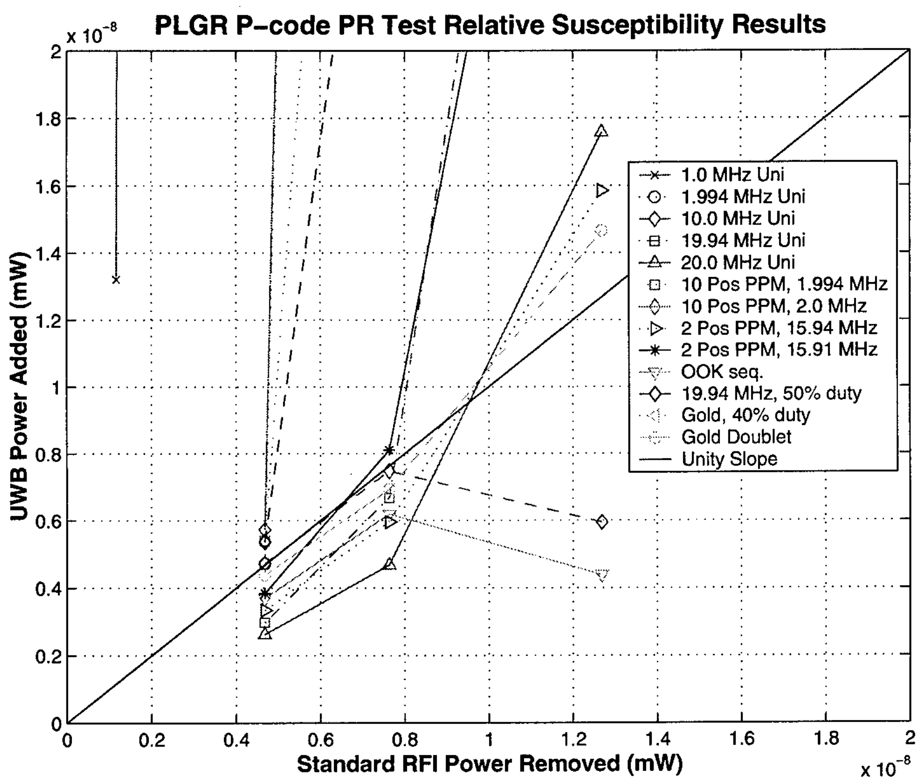


Figure 12~~12~~. Plot of PLGR P-code PR test results, x axis and y axis equal.

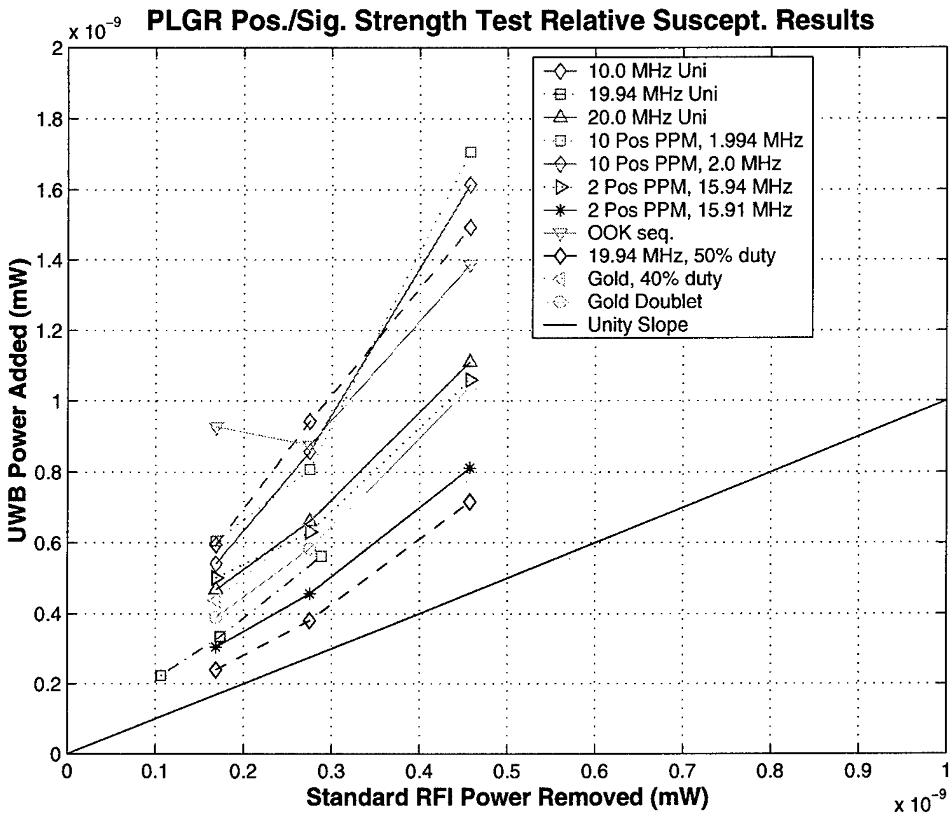


Figure 13~~13~~. Plot of PLGR Position/Signal Strength test results, y axis two times x axis.

This table summarizes whether the UWB interference had more impact than an equivalent level of added white noise interference.

--	indicates	much less	effect than standard interferer
-	indicates	less	effect than standard interferer
0	indicates	same	effect as standard interferer
+	indicates	more	effect than standard interferer
++	indicates	much more	effect than standard interferer

+/- these interference effects change relation with standard interferer and vary with UWB signal strength

ND No Data

??? Unclear

Table 33. UWB Susceptibility, GPS Data Results Summary

UWB waveform	MAGR P-code pseudorange error variance Equivalence	MAGR CA code pseudorange error variance Equivalence	MAGR position/ signal strength Equivalence	PLGR P-code pseudorange error variance Equivalence	PLGR position/ signal strength Equivalence
1.0 MHz Unif. PRF	--	--	--	--	ND
1.994 MHz Unif. PRF	--	--	--	0/--	ND
10.0 MHz Unif. PRF	0/++	-	--	0/++	--
19.94 MHz Unif. PRF	0/--	++	0	0/--	-
20.00 MHz Unif. PRF	+/-	-/--	-	+/-	-
1.994 MHz nom PRF, 10-pos dither	--	--	--	0/--	--
2.000 MHz nom PRF, 10-pos dither	--	--	--	0/--	--
15.94 MHz nom PRF 2-pos dither	0/-	-/--	0/-	+/-	-
15.91 MHz nom PRF 2-pos dither	0/--	0/???	0/-	0/--	-
On/Off Keying	0/++	-/0	-	0/++	--
19.94 MHz PRF, 50% DF	--	++	0/-	0/--	0/-
"Gold" doublet 40%	--	--	0/-	ND	-
"Gold" doublet 100%	0	0	-	0/-	-

The results of the tests demonstrated that for most of the thirteen UWB test waveforms and test types, the AN/ASN-163 and the AN/PSN-11 GPS receivers were less susceptible to the UWB waveforms than to an equivalent white noise or CW interferer. This means that for most of the waveforms, UWB interference caused an equivalent EMI effect in the receivers at higher power levels than for the white noise or CW levels. Only in a few cases was relative susceptibility of the UWB waveform significantly worse than the standard RFI. For example, a significantly worse impact occurred for the MAGR and PLGR P-code PR tests for two waveforms. These were the 10.0 MHz uniform and OOK waveforms, but only for the highest power back-off level. Also, for the MAGR C/A-code PR test, the 19.94 MHz uniform PRF and 19.94 MHz uniform PRF with a 50% duty factor also caused significantly worse impact than the broadband noise standard RFI.

In general, the impact of UWB interference on signal strength was more benign than for the pseudorange performance. Pseudorange performance exhibited much more varied performance depending strongly on the waveform type, as alluded to in the previous paragraph. A possible explanation of this behavior is that the manner in which the UWB interference impacts the C/N_0 detector in the receivers is significantly different than UWB interference on the PR measurement generation processing. Similar effects have been documented with regard to the effects of partial band interferers on GPS receivers.

The relative susceptibility data and plots presented in the report provide an aggregate impact of UWB RFI over multiple, tracked satellites. In generating the aggregate measures, it was noted that significant satellite to satellite performance variation was more pronounced fort the C/A-code PR test than for the P-code PR tests. This is expected due to the potential of interaction between the discrete spectral characteristics of some of the UWB waveforms tested with the discrete spectral lines of the C/A-code GPS signal.

In one case, the MAGR C/A-code PR test for the 2 position dithered 15.91 MHz nominal PRF waveform, it was not possible to determine the relative susceptibility impact for the 4 dB and No Noise back-off levels. This was due to a very large difference in expected PR performance compared to reported signal levels from the receiver. Though this test for this waveform was repeated twice, the data for these two back-off was inconclusive in determining the relative susceptibility.

For the 1.0 and 1.994 MHz uniform PRF waveforms for the PLGR position/signal strength test, the collected data files were corrupt and so could not be post-processed before the test set-up was disassembled.

SECTION 4 DESCRIPTION OF EMI TESTS AND DETAILED RESULTS

4.1 RECEIVER SUSCEPTIBILITY MEASUREMENT APPROACH

4.1.1 Basic Test Method Description

The basic test method is essentially a relative susceptibility measurement of UWB RFI effect compared to that of the standard RFI, either broadband noise or an in-band CW interference tone. The test method concept is illustrated by the curves in Figure 14~~Figure 14~~ assuming the PR standard deviation is the performance metric of interest and broadband (BB) noise is the standard RFI. The same approach applies if a different performance metric is used and/or the standard RFI is some other type of signal.

For example given in Figure 14~~Figure 14~~, the test method calls for a standard RFI to be injected into the receiver and increased in power level until the accuracy limit is exceeded. The curve labeled "BB Noise Only" plots the baseline GPS receiver pseudorange measurement error standard deviation with the standard RFI, which in this case is broadband noise. As indicated, the total interference input power at the accuracy limit is N_{ACC}. This constitutes the baseline noise normalization. The accuracy limit is determined based on signal level assumptions that model a particular, relevant interference environment.

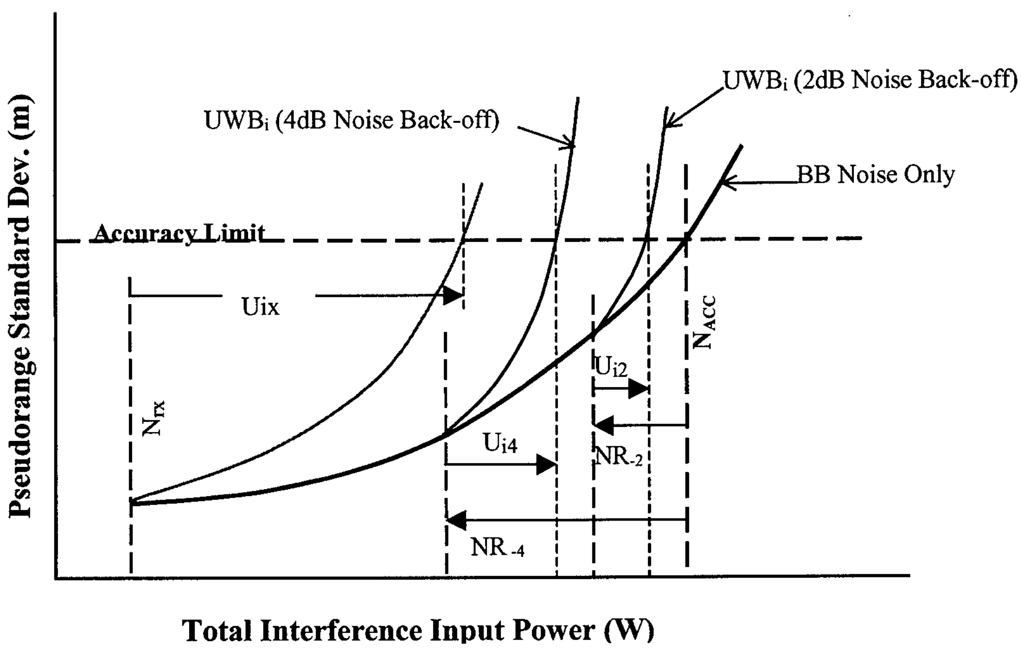


Figure 14~~14~~. Broadband Noise Normalization and Partial UWB RFI Substitution Method

The test method then calls for making three additional sets of measurements for each UWB interference waveform where UWB RFI power replaces a known portion of the baseline standard interference power. One set has the standard interferer power reduced 2 dB below N_{ACC} (2 dB back-off curve), a second has the standard interferer 4 dB below N_{ACC} (4 dB back-off curve), and the third has all the injected standard RFI removed. The third measurement is illustrated by the red curve in Figure 14~~Figure 14~~ and is performed to maintain compatibility with the Netex Master Test Plan. From the RFI effects standpoint, the standard RFI equivalency of a UWB waveform comes from a comparison of the UWB power values added back (U_{i2}, U_{i4} and U_{ix}) to give the same standard deviation with the known amount of standard interference power they replaced (NR_{-2}, NR_{-4} and $NR_{-\infty}$). From the above example, UWB power values U_{i2}, U_{i4} and U_{ix} are less than the broad band noise powers, NR_{-2}, NR_{-4} and $NR_{-\infty}$, they replaced to give equal RFI effect. Thus UWB waveform, *i*, has a greater RFI effect than broadband noise of equivalent power.

The values for added UWB power, U_{i2}, U_{i4} and U_{ix}, can then be plotted against the associated standard RFI power removed values, NR_{-2}, NR_{-4} and $NR_{-\infty}$. This plot demonstrates the standard RFI equivalency of the UWB waveform as a function of the various back-off levels. Multiple standard RFI equivalency factors can be computed for each waveform given the three data points for each plot. The standard RFI equivalency in dB is equal to 10 $\log_{10}$[slope]. It should be noted that the data points will not necessarily lie on a straight line.

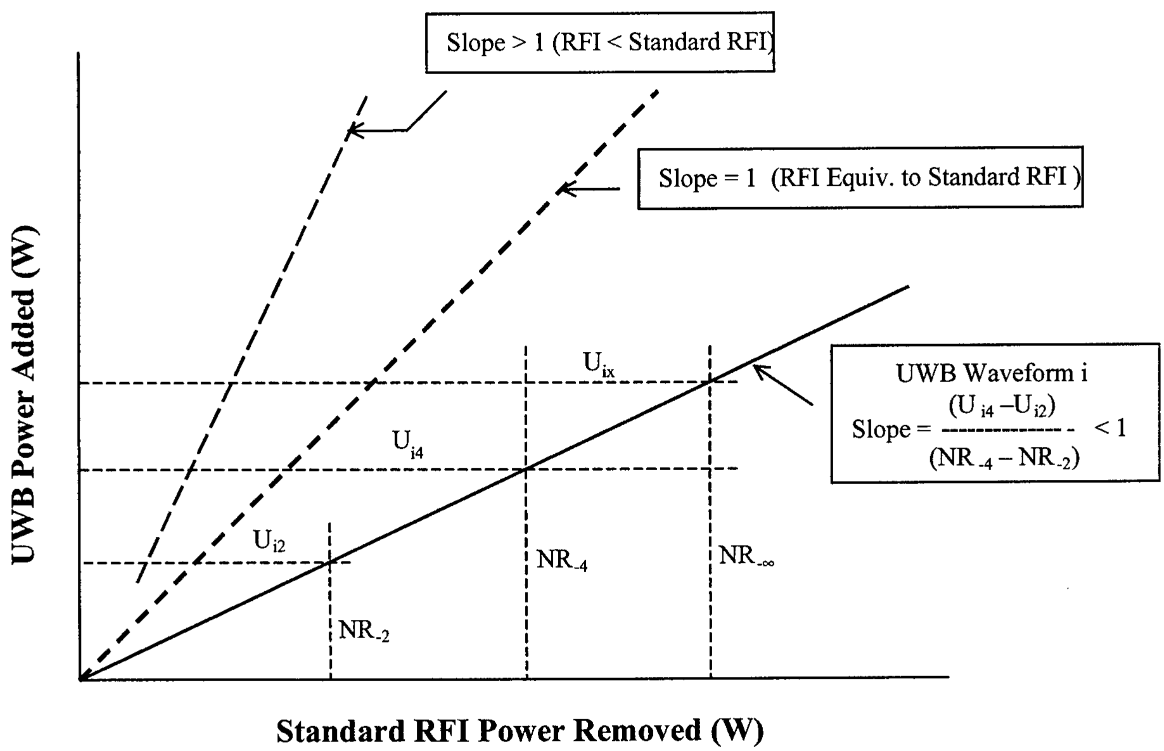


Figure 15~~15~~. Noise Equivalency Factor Curves.

The curves in Figure 15~~Figure 15~~ illustrate three possibilities for the standard RFI equivalency. Namely, a slope less than 1 indicates that the waveform has a more harmful RFI effect to GPS than the same amount of standard RFI. A unity slope indicates equivalent RFI effect to standard RFI, while a slope greater than 1 indicates less harmful RFI effect.

Another sort of outcome is also possible. If a line connecting the origin to the three UWB power points shows significant curvature (i.e., greater than the measurement error for the points), it indicates that the UWB signal is not adding linearly to the standard RFI. The standard RFI equivalency factor (slope) is still defined but it becomes a function of the amount of broadband RFI present in the particular scenario.

The equivalency factor (in dB) is used in an RFI link budget to correct the RFI signal allotment so the actual UWB emission gives the same RFI effect. That is, once an allocation for a particular amount of RFI is made to a UWB emitter, the standard RFI equivalency factor (dB) is added to the total RFI allotment to give the actual permitted UWB RFI power. If the RFI equivalency factor for a particular UWB emitter waveform is –X dB, then the permitted UWB emission level is X dB less than the RFI allotment to UWB.

4.1.2 Comments on the Basic Test Method

One advantage of the basic test method is that it normalizes individual receiver UWB RFI susceptibility performance to well-understood RFI effects, broadband noise and in-band CW interferer. This normalization is beneficial since, regardless of how much the receiver standard RFI susceptibility exceeds the required value, UWB susceptibility is referenced to the standard RFI value so individual receiver performance variation within a given receiver type is mostly removed. The standard RFI equivalency factors are also useful for comparing and categorizing UWB waveforms in terms of RFI effect. The standard RFI reduction values (-2 dB and -4 dB) were chosen as well-spaced, reasonable values from a measurement standpoint.

4.1.3 Performance Metrics and Standard RFI for the GPS Receiver Test Types

For the P-code and C/A-code pseudorange testing, the GPS receiver performance parameter chosen for determining the relative RFI effect is the pseudorange error standard deviation. This parameter was chosen because it is relatively sensitive to degradation prior to the onset of receiver tracking loop loss of lock. The standard RFI for the PR tests is broad band noise. This choice was based on following the UWB interference testing methodology developed under FAA funding on civil aviation GPS receivers. Both P-code and C/A-code PR testing was performed on the MAGR, whereas only P-code PR testing was performed on the PLGR. The rationale for performing C/A-code PR testing on the MAGR is that the MAGR is an airborne receiver and military aircraft must be able to operate in civil airspace where certification requirements usually dictate the use of C/A-code tracking.

For the position and signal strength testing, the degradation of the C/N_0 level was chosen

for determining the relative RFI effect. This test was based on a legacy MAGR qualification test for conducted susceptibility. The legacy susceptibility qual test had a combined metric which involved both C/No level and position. However, in our testing we ignored the position error component of the metric since preliminary testing indicated that position errors were not correlated with standard RFI or UWB RFI. The standard RFI for these tests is an in-band CW tone. There is additionally a fixed amount of added broadband noise injected into the receiver with the standard RFI tone. The broadband noise in this case is not part of the standard RFI but serves to set the baseline C/N_0 level from which the degradation due to RFI is measured. This test was performed on both the MAGR and the PLGR.

4.1.4 Standard RFI Level Determination

Before UWB relative susceptibility tests can be performed it was necessary to establish the baseline standard RFI level and the accompanying performance threshold metric value. Each of the five test types (three for MAGR and two for PLGR) have their own standard RFI levels and threshold values.

For the position and signal strength tests for the PLGR and MAGR the determination of the standard RFI level was straightforward. Based on the legacy MAGR qual test, the performance threshold was a plus or minus 2 dB deviation in C/N_0 from a reference value of 30 dB-Hz, where the standard RFI is an inband CW tone. In order to determine the appropriate standard RFI level, all that was required was to monitor the displayed C/N_0 value as the CW power was increased until the C/N_0 had deviated by 2 dB from the nominal. This CW power was then recorded for reference in conducting the UWB relative susceptibility tests. The observed 2 dB deviation for both the PLGR and MAGR was a 2 dB degradation in C/N_0. The procedure for setting the reference 30 dB-Hz level, prior to the injection of the standard RFI tone, is given in the detailed test plan documents. It involved setting a particular PCSG simulator signal output level following by injecting broadband noise until the 30 dB-Hz level was achieved.

However the determination of the baseline standard RFI level and accompanying performance threshold for the PR tests was considerably more complicated. The approach taken for these tests was to mimic a representative antenna installation model, illustrated by the block diagram in Figure 16~~Figure 16~~. Assuming a -160 dBW signal, which is the minimum C/A-code GPS signal power as specified in the WAAS MOPS RTCA DO-229C, at the antenna, the overall gain of the installation model of 9 dB yields a -151 dBW signal at the receiver input. Given an assumed 100 K sky noise temperature and the 4 dB Noise Figure of the preamplifier, which are typical values, the equivalent noise temperature at the GPS receiver input is 12051.2 K. This gives a noise power of -188 dBW in a one hertz bandwidth, which is 16 dB above the value for room temperature noise of -204 dBW, also in a 1 Hz bandwidth. It was further assumed that the "worst case" interference environment would contribute an additional 3 dB of broadband noise, so the overall standard RFI level for the C/A-code PR test was 19 dB above room temperature noise injected into the receiver. Since the P-code signal level transmitted from the GPS satellites is 3 dB lower than the C/A-code signal, the same background and interference environment would give a 3 dB lower C/N_0 for P-code than for C/A-code

given the same antenna installation configuration. In order to achieve this, the standard RFI level of injected noise was increased for the P-code PR test to 22 dB above room temperature while using the same GPS signal level of -151 dBW.

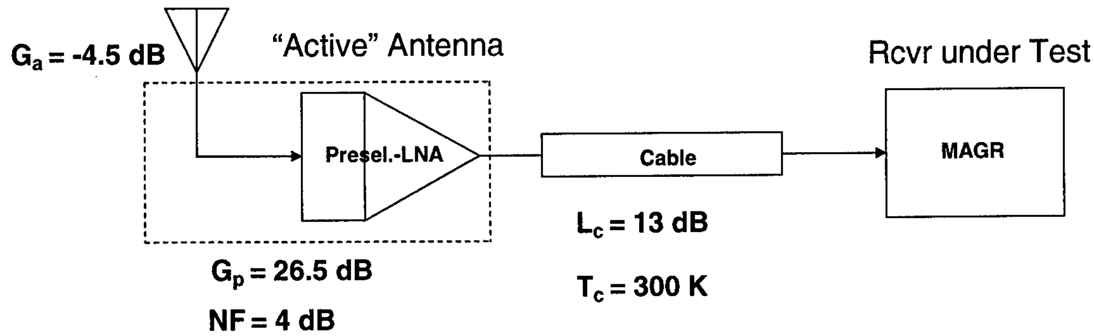


Figure 16~~16~~. Antenna Installation Model for PR Test Standard RFI Reference Level Determination.

4.1.5 Test Measurement Setup for Baseline Performance Determination

Separate test plans and procedure documents were generated for each of the two GPS receivers. These were included in the Master Netex Test Document as appendices. The test plans and procedures include a high degree of detail in the test measurement methods for each of the GPS receivers. This information will not be repeated in this report, but instead an overview of the general test techniques, without the GPS receiver specific details of the measurement methods that are detailed in the test procedure, will be presented.

The GPS UWB EMI performance evaluation test set-up is shown in Figure 17~~Figure 17~~. A Collins PCSG GPS satellite constellation simulator was used to generate the desired signal for the GPS receivers. GPS serial output data was collected and post processed to determine GPS performance. For the baseline performance determination no UWB power was input to the GPS receiver under test.

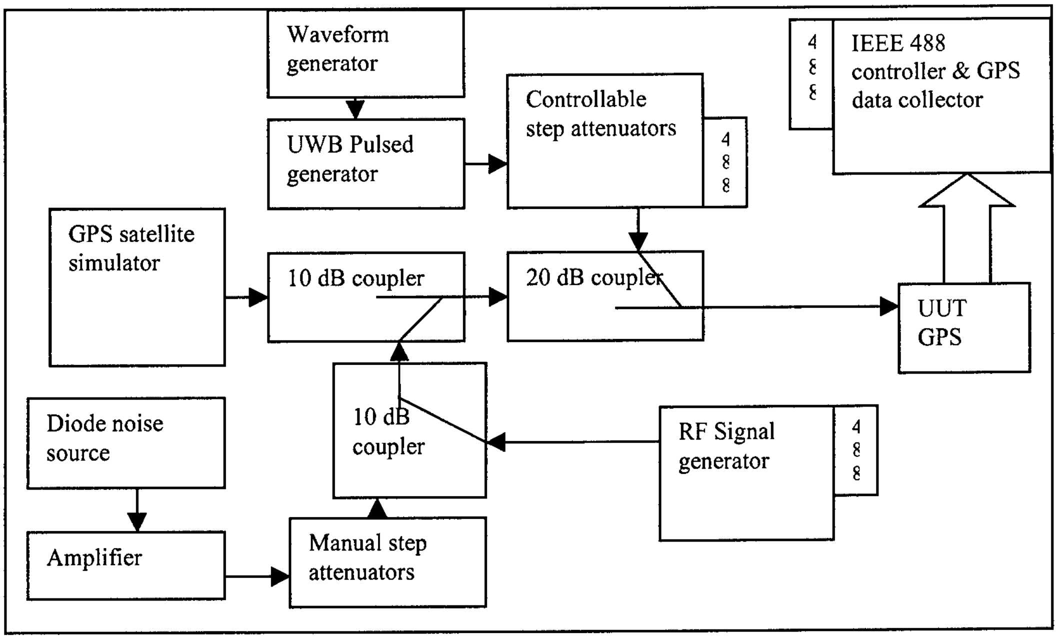


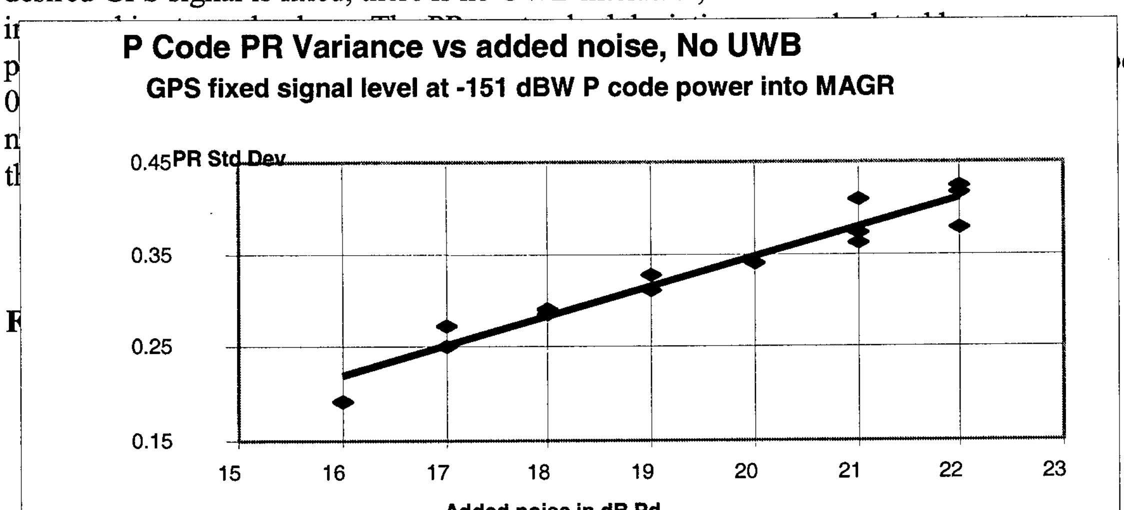
Figure 1717. GPS Receiver Test Set-Up

4.1.6 Receiver Baseline Performance Threshold Test Procedures

As mentioned in a previous section the performance threshold for the position and signal strength tests was a signal degradation of 2 dB and this was based on the legacy MAGR qualification test. However, for the PR tests the performance threshold must be determined by post-processing the collected pseudorange data in order to determine the standard deviation based on the GPS signal and standard RFI levels defined in Section 4.1.4.

The baseline PR performance was determined by adding know levels of noise to a fixed desired signal. With a fixed level of desired signal from the GPS simulator, stepped calibrated levels of broadband noise were added to the receiver input signal. The raw data to determine pseudorange standard deviation (PRerr) was collected for each step. Different PRerr threshold test conditions were required for CA-code and P-code GPS tracking. To determine the PRerr, the collected data was post-processed.

Figure 18~~Figure 18~~ illustrates the MAGR GPS receiver baseline performance curve. The desired GPS signal is fixed, there is no UWB interferer, and the added noise level is



4.2 UWB INTERFERENCE TESTS GPS

The objective of these EMI tests was to determine the relative susceptibility of an AN/ASN-163 and AN/PSN-11 GPS receivers to UWB interfering signals. In like manner as the receiver baseline performance testing, complete details of the UWB interference test measurement methods for each of the GPS receivers are given in the respective appendices of the Master Netex Test Document. This information will not be repeated in this report, but instead an overview of the general test techniques, without the GPS receiver specific details of the measurement methods that are detailed in the test procedure documents.

The same test setup is used for both the pseudorange standard deviation tests and the Position/Signal Strength tests. The test set up is shown in Figure 17~~Figure 17~~.

4.2.1 Test Procedure- Pseudorange Standard Deviation Tests

For the GPS pseudorange error variance test, the general test technique is outlined below.

1. Given the standard RFI level given in Section 4.1.6, for each test the level of the added standard RFI power, i.e., broadband noise, is reduced 2 dB from the standard interference level. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the pseudorange standard deviation. The power of the added UWB signal that produces the threshold value for the pseudorange standard deviation is recorded as the 2 dB backoff level. The standard deviation is determined by post-processing the recorded PR data.
2. The level of the added broadband noise is reduced 4 dB from the standard interference level. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the pseudorange standard deviation. The power of the added UWB signal that produces the threshold value for the pseudorange standard deviation is recorded as the 4 dB backoff level. The standard deviation is determined by post-processing the recorded PR data.
3. All of the added broadband noise is removed. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the pseudorange standard deviation. The power of the added UWB signal that produces the threshold value for the pseudorange standard deviation is recorded as the no added noise level. The standard deviation is determined by post-processing the recorded PR data.
4. Steps 1 through 3 were repeated for each UWB waveform.
5. Steps 1 through 4 were repeated for each receiver in each defined P-code and/or CA-code tracking mode.

4.2.2 Test Procedure- Position/Signal Strength Tests

For the GPS position and signal strength test, the general test technique is outlined below.

1. The level of the CW signal is reduced 2 dB from the standard interference level. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the position and signal strength test. The power of the added UWB signal that produces the threshold value for the position and signal strength test is recorded as the 2 dB backoff level.
2. The level of the CW signal is reduced 4 dB from the standard interference level. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the position and signal strength test. The power of the added UWB signal that produces the threshold value for the position and signal strength test is recorded as the 4 dB backoff level.
3. The CW signal is removed. UWB signal is added to the receiver RF signal input with increasing strength until the GPS receiver performance is degraded back to the threshold value for the position and signal strength test. The power of the added UWB signal that produces the threshold value for the position and signal strength test is recorded as the no added noise level.
4. Steps 1 through 3 were repeated for each UWB waveform.
5. Steps 1 through 4 were repeated for each receiver.

4.2.3 Data Post-Processing

Detailed descriptions of the post-processing procedures for each of the five test types are given the MAGR and PLGR test plan documents. A general description of the post-processing approach will be provided.

For the three PR tests (P-code for MAGR and PLGR and C/A-code for MAGR), data was collected for multiple UWB power levels (determined by variable attenuator settings) for each back-off level. For example, in most cases three attenuator settings were used for each of the three backoff levels described above. Hence, nine attenuator settings, each having a data collection interval of 5 minutes, were run for each of the 13 waveforms for each PR test.

The collected data for these attenuator settings was post-processed to determine the UWB power at which the performance threshold was achieved. If the threshold was not achieved at one of the attenuator settings used for that backoff level, the data was interpolated to determine the attenuator value. For each attenuator setting used, data was collected for all of the tracked GPS satellites. The data for each satellite was post-processed and the standard deviation over the data collection interval was computed. For a particular attenuator setting, average of the computed standard deviations for the multiple satellites was used to compute the attenuator value where the performance threshold was achieved.

Figure 19~~Figure 19~~ shows an example of the multiple satellite post-processed standard deviations along with the standard deviation averages used in determining the UWB power where the performance threshold is achieved. This example is for the MAGR C/A-code PR test for the 20 MHz uniform UWB waveform and shows the data for all three of the back-off levels. In the figure, the standard deviation averages for each back-off level are connected by black lines, which are used to interpolate the attenuator value for threshold determination. Also, the individual satellite data for the 4 dB back-off level are connected by colored lines to more easily discriminate those data points from the other two back-off levels. Note that for this waveform and test type there is significant satellite to satellite variation in the computed standard deviations. The average curve provides an overall performance measure and is not directly representative of any particular satellite's performance. For C/A-code PR performance, satellite to satellite variation is not unexpected due to spectral lines in the UWB waveform interacting with individual spectral lines in the C/A-code spectrum.

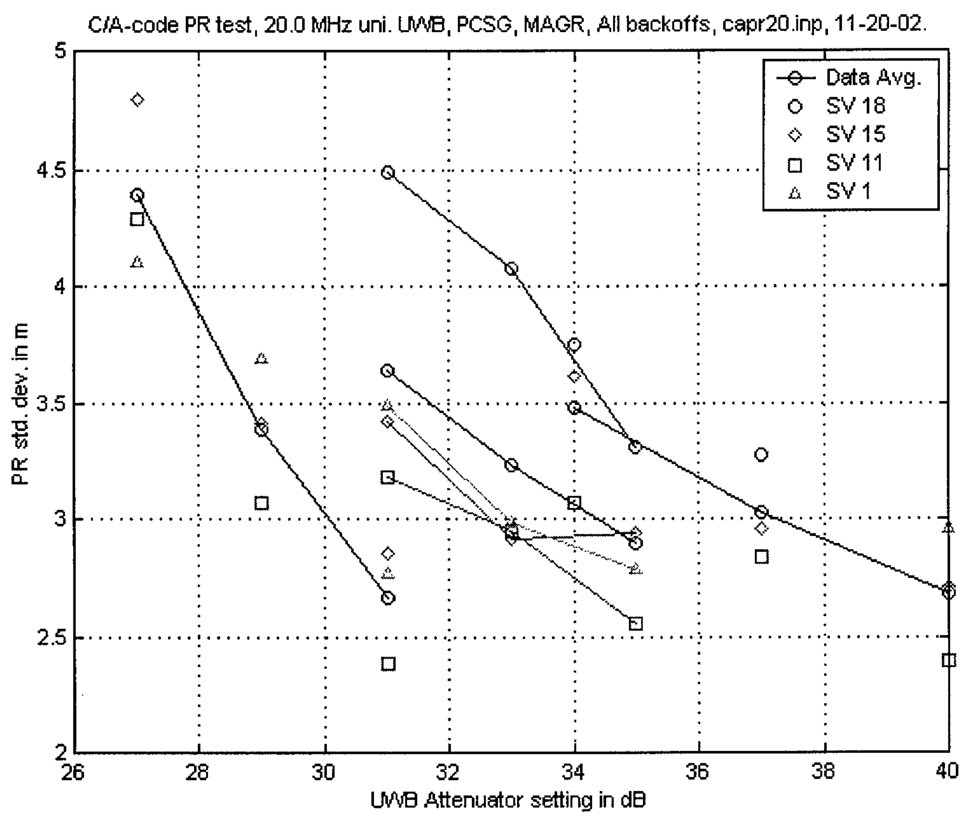


Figure 19~~19~~. Plot of raw and average standard deviations for MAGR C/A-code PR test for 20 MHz uniform UWB waveform for all backoff levels and attenuator settings.

For the Position/Signal Strength test, data was collected for multiple UWB attenuator settings for each back-off level. For each UWB attenuator setting the average C/N_0 over all the tracked satellites was computed for use in determining the attenuator value at the which the 2 dB threshold was achieved. The C/N_0 for individual satellites was not

computed, but instead all the C/N_0 was aggregated and used to compute the average value. An example of the plotted data for determining attenuator setting where the performance threshold is achieved is given in Figure 20~~Figure 20~~.

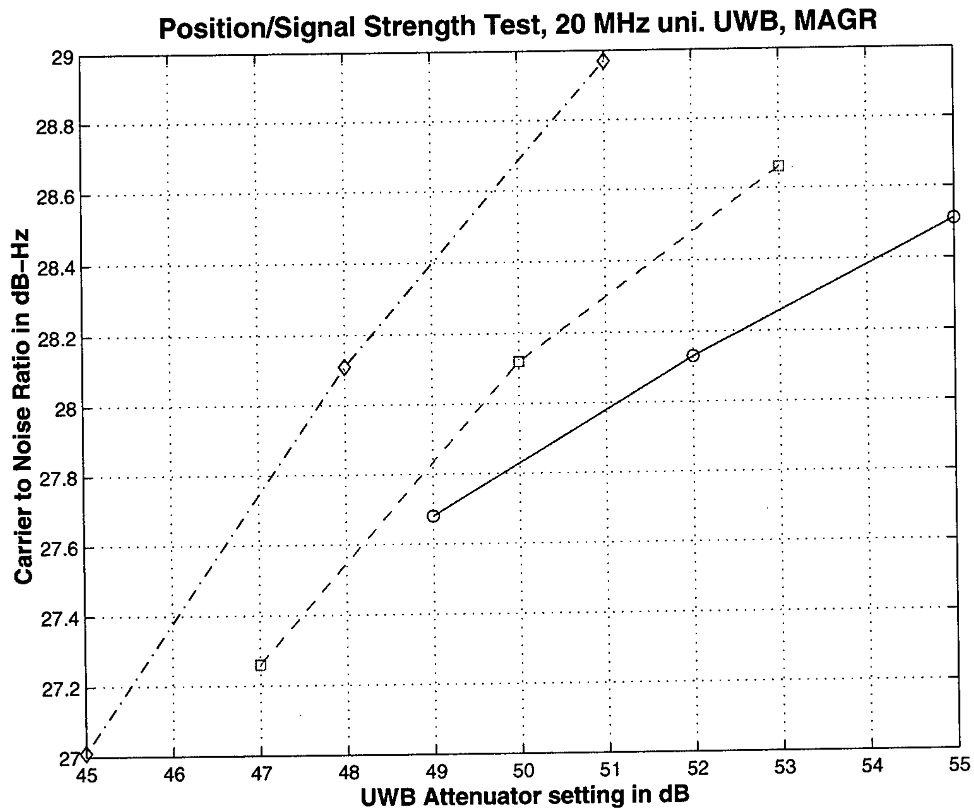


Figure 20~~20~~. Plot of average carrier to noise ratio for all three back-off levels and associated attenuator settings for the MAGR position/signal strength test with the 20 MHz uniform UWB waveform.

4.2.4 Test Output Data

The primary, post-processed output data from the test types are the UWB attenuator values at which the performance thresholds for the respective test types are achieved. The attenuator values combined with calibrated measurements of the UWB waveform power output by the UWB generator in the 20 MHz bandwidth of the GPS receiver were used to compute the exact UWB power input to the GPS receiver. This power data can then be used to compute equivalency factors or plotted to visually inspect the relative susceptibility of the UWB waveforms. The method used for measuring the UWB waveform power in the 20 MHz input bandwidth of the GPS receiver is given in Appendix B. In order to compute equivalency factors or plot the relative susceptibility data, the standard RFI power level needs to be known in order to correctly compute power removed compared to UWB power added.

The tables below provide the measured UWB power levels, attenuator settings, and

standard RFI levels for each of the five test types. Note that for the three PR test types the standard RFI power level for the 1 MHz uniform waveform was +16 dB Pd. This modified standard RFI level was used because the UWB generator did not output enough power for this waveform for the PR performance threshold to be achieved given the normal standard RFI level used for all the other waveforms. Also, for the two position/signal strength test types, the power level of the standard RFI CW tone was not always identical due to signal generator variation from one waveform test to another test.

In all the following tables in this document, 'nan' mean that no data value is available for that table entry.

Table 44. MAGR P-code PR Test Data

Waveform	Measured power into receiver in dBm	2 dB backoff atten	4 dB backoff atten	No noise backoff atten	Standard RFI Ref. level (Pd dB)
1.0 MHz UNI PRF	-56.29	15.80	-0.20	nan	16
1.994MHz UNI PRF	-53.26	22.50	14.50	2.8	22
10 MHz UNI PRF	-46.01	37.00	35.90	36	22
19.94 MHz 100%	-43.00	39.70	32.50	26.6	22
20 MHz UNI PRF	-42.80	43.50	41.40	34.1	22
10POS PPM 1.994 MHz NOM	-53.18	22.30	15.90	2.4	22
10POS PPM 2 MHz NOM	-53.17	23.90	15.50	2.6	22
2POS PPM 15.94MHz NOM	-43.75	40.60	38.20	31.6	22
2POS PPM 15.91MHz NOM	-43.66	39.00	33.80	28.2	22
OOK (ser #3 UWB)	-45.83	36.30	35.00	37.1	22
19.94 MHz 50% OF 2 MS	-45.95	23.95	15.5	2.58	22
Gold 40 % (ser #3 UWB)	-40.34	38.34	25.5	nan	22
Gold (ser #3 UWB)	-36.84	46.00	44.40	42	22

Table 55. MAGR C/A-code PR Test Data

Waveform	Measured power into receiver in dBm	2 dB backoff atten	4 dB backoff atten	No noise backoff atten	Standard RFI Ref. level (Pd dB)
1.0 MHz UNI PRF	-56.29	17.6	-0.7	nan	16
1.994MHz UNI PRF	-53.26	27.1	11.7	4.6	19
10 MHz UNI PRF	-46.01	35.7	34	32.8	19
19.94 MHz 100%	-43.00	51.4	49.2	nan	19
20 MHz UNI PRF	-42.80	39	35.6	30.6	19
10POS PPM 1.994 MHz NOM	-53.18	25.2	17.3	5	19
10POS PPM 2 MHz NOM	-53.17	22.9	14.4	4.2	19
2POS PPM 15.94MHz NOM	-43.75	37.6	33.8	29.1	19
2POS PPM 15.91MHz NOM	-43.66	44.6	nan	nan	19
OOK (ser #3 UWB)	-45.83	36.7	34.8	35.9	19
19.94 MHz 50% OF 2 MS	-45.95	47.6	45.2	nan	19
Gold 40 % (ser #3 UWB)	-40.34	39.4	25.9	nan	19
Gold (ser #3 UWB)	-36.84	48.1	46.6	44.6	19

Table 66. MAGR Position/Signal Strength Test Data

Waveform	Measured power into receiver in dBm	2 dB backoff atten	4 dB backoff atten	No noise backoff atten	Standard RFI Ref. level (dBm)
1.0 MHz UNI PRF	-56.29	27.50	24.00	nan	-94.4
1.994MHz UNI PRF	-53.26	35.70	33.70	30.5	-94.4
10 MHz UNI PRF	-46.01	45.40	44.90	42.9	-93.4
19.94 MHz 100%	-43.00	52.30	51.40	48.6	-93.4
20 MHz UNI PRF	-42.80	51.10	49.60	47.7	-93.4
10POS PPM 1.994 MHz NOM	-53.18	37.80	35.10	30.8	-93.4
10POS PPM 2 MHz NOM	-53.17	36.80	34.70	31.3	-93.4
2POS PPM 15.94MHz NOM	-43.75	51.40	49.40	46.8	-93.4
2POS PPM 15.91MHz NOM	-43.66	52.20	49.50	47.2	-93.4
OOK (ser #3 UWB)	-45.83	45.00	44.20	42.6	-93.4
19.94 MHz 50% OF 2 MS	-45.95	53.4	49.2	45.2	-94.4
Gold 40 % (ser #3 UWB)	-40.34	55.2	52.1	nan	-94.4
Gold (ser #3 UWB)	-36.84	56.20	54.60	52.8	-93.4

Table 77. PLGR P-code PR Test Data

Waveform	Measured power into receiver in dBm	2 dB backoff atten	4 dB backoff atten	No noise backoff atten	Standard RFI Ref. level (Pd dB)
1.0 MHz UNI PRF	-56.29	22.5	6.5	nan	16
1.994MHz UNI PRF	-53.26	30	14.75	nan	22
10 MHz UNI PRF	-46.01	37.25	35.25	36.25	22
19.94 MHz 100%	-43.00	42.25	38.75	30.25	22
20 MHz UNI PRF	-42.80	43	40.5	34.75	22
10POS PPM 1.994 MHz NOM	-53.18	29.5	19.5	nan	22
10POS PPM 2 MHz NOM	-53.17	29.25	14.75	nan	22
2POS PPM 15.94MHz NOM	-43.75	41	38.5	34.25	22
2POS PPM 15.91MHz NOM	-43.66	40.5	37.25	30.25	22
OOK (ser #3 UWB)	-45.83	38.5	36.25	37.75	22
19.94 MHz 50% OF 2 MS	-45.95	36.75	29	nan	22
Gold 40 % (ser #3 UWB)	-40.34	nan	nan	nan	22
Gold (ser #3 UWB)	-36.84	46.75	44.75	41.5	22

Table 88. PLGR Position/Signal Strength Test Data

Waveform	Measured power into receiver in dBm	2 dB backoff atten	4 dB backoff atten	No noise backoff atten	Standard RFI Ref. level (dBm)
1.0 MHz UNI PRF	-56.29	No Data	No Data	No Data	No Data
1.994MHz UNI PRF	-53.26	No Data	No Data	No Data	No Data
10 MHz UNI PRF	-46.01	46.25	44.25	42.25	-93.4
19.94 MHz 100%	-43.00	53.5	51.75	49.5	-95.4
20 MHz UNI PRF	-42.80	50.5	49	46.75	-93.4
10POS PPM 1.994 MHz NOM	-53.18	39	37.75	34.5	-93.4
10POS PPM 2 MHz NOM	-53.17	39.5	37.5	34.75	-93.4
2POS PPM 15.94MHz NOM	-43.75	49.25	48.25	46	-93.4
2POS PPM 15.91MHz NOM	-43.66	51.5	49.75	47.25	-93.4
OOK (ser #3 UWB)	-45.83	44.5	44.75	42.75	-93.4
19.94 MHz 50% OF 2 MS	-45.95	50.25	48.25	45.5	-93.4
Gold 40 % (ser #3 UWB)	-40.34	53.25	51.5	nan	-93.4
Gold (ser #3 UWB)	-36.84	57.25	55.5	53	-93.4

In computing equivalency factors or plotting the power removed versus power added data, the power removed must first be computed based on the standard RFI type and power level. These values are given below in .

Table 99. Power Removed table for all test types.

Standard RFI Type and Power Level	2 dB backoff (mW)	4 dB backoff (mW)	No noise backoff (mW)
Broadband noise, 22 Pd dB	0.4681e-8	0.7635e-8	1.2685e-8
Broadband noise, 19 Pd dB	0.2346e-8	0.3827e-8	0.6358e-8
Broadband noise, 16 Pd dB	0.1176e-8	0.1918e-8	0.3186e-8
CW tone, -93.4 dBm	0.1687e-9	0.2751e-9	0.4571e-9
CW tone, -94.4 dBm	0.1340e-9	0.2185e-9	0.3631e-9
CW tone, -95.4 dBm	0.1064e-9	0.1736e-9	0.2884e-9

4.2.5 Equivalency Factor Data Tables

Given the standard RFI power removed and UWB power added data, equivalency factors

may be computed for different choices of point pairs. In this report, equivalency factors are presented for the three segments defined below in Figure 21~~Figure 21~~. Note that for the actual test data, the slopes may be either less or greater than unity. For the three segments, both slopes and the slope values in dB are provided in Table 10~~Table 10~~ to Table 14~~Table 14~~ for each waveform and test type. A table entry of 'nan' means that no data value is available. Also, in some cases the slope value in dB was undefined because the raw slope value was negative.

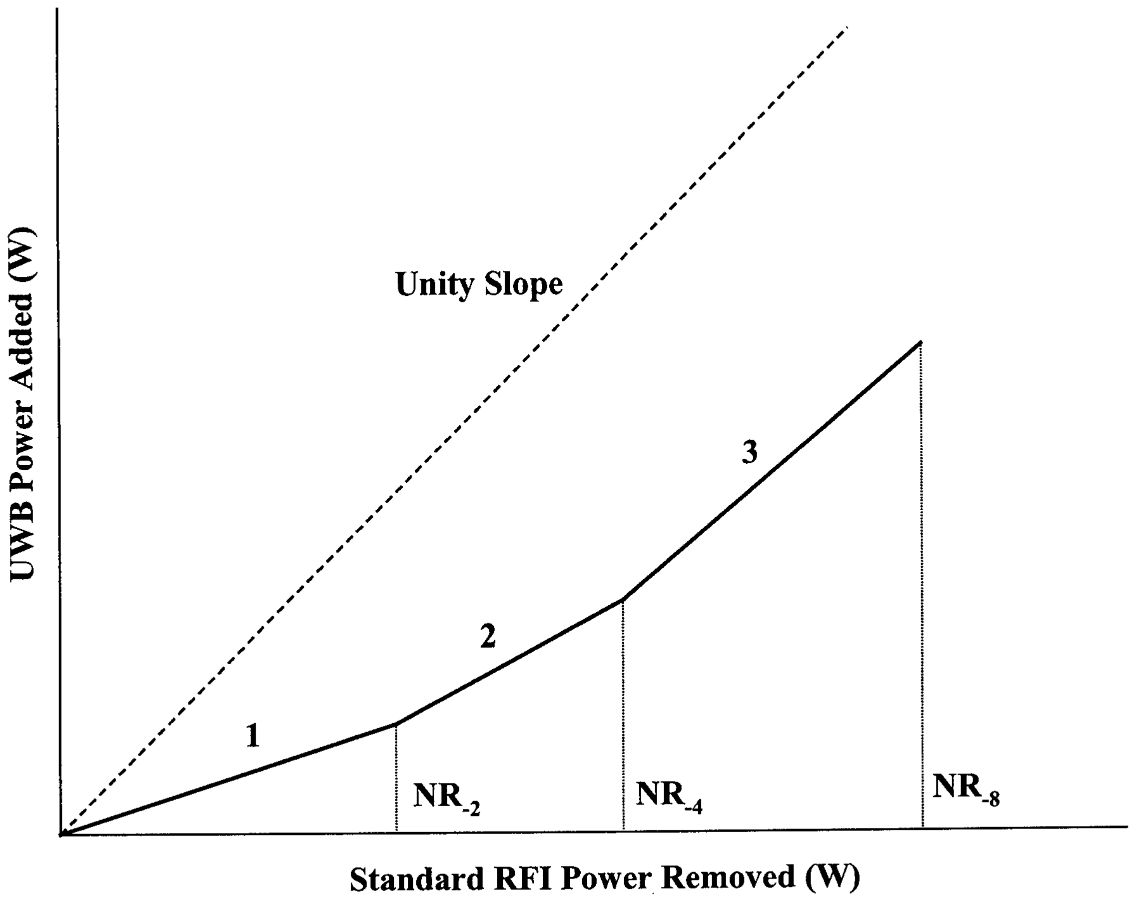


Figure 21~~21~~. Line segments for which equivalency factors are reported are number 1, 2 and 3.

Table 10~~10~~. MAGR P-code PR Equivalency Factor Data

Waveform	Segment 1	Segment 2	Segment 3	Log Segment 1	Log Segment 2	Log Segment 3
1.0 MHz UNI PRF	52.55241	3232.569	nan	17.20593	35.09548	nan
1.994MHz UNI PRF	5.671022	47.71436	457.4114	7.536614	16.78649	26.60307
10 MHz UNI PRF	1.068222	0.487931	-0.02904	0.286614	-3.11642	undefined
19.94 MHz 100%	1.147259	7.722922	16.13148	0.596614	8.877816	12.07674
20 MHz UNI PRF	0.500797	0.493455	3.290195	-3.00339	-3.06753	5.172217
10POS PPM 1.994 MHz NOM	6.04869	32.25485	523.435	7.816614	15.08595	27.18863
10POS PPM 2 MHz NOM	4.194318	39.33573	497.5582	6.226614	15.94787	26.96844
2POS PPM 15.94MHz NOM	0.784624	0.917336	4.513195	-1.05339	-0.37471	6.544841
2POS PPM 15.91MHz NOM	1.157874	4.240801	9.349605	0.636614	6.274479	9.707932
OOK (ser #3 UWB)	1.308161	0.723384	-0.62714	1.166614	-1.40631	undefined
19.94 MHz 50% OF 2 MS	21.86056	207.7908	2636.038	13.39661	23.17626	34.20952
Gold 40 % (ser #3 UWB)	2.895085	83.63692	nan	4.616614	19.22398	nan
Gold (ser #3 UWB)	1.110865	0.784113	1.098115	0.456614	-1.05622	0.406478

Table 11. MAGR C/A-code PR Equivalency Factor Data

Waveform	Segment 1	Segment 2	Segment 3	Log Segment 1	Log Segment 2	Log Segment 3
1.0 MHz UNI PRF	34.72104	3665.426	nan	15.40593	35.64124	nan
1.994MHz UNI PRF	3.923485	209.2838	520.6095	5.93672	23.20736	27.16512
10 MHz UNI PRF	2.875226	2.18212	1.254543	4.58672	3.388787	0.984855
19.94 MHz 100%	0.154765	0.161703	nan	-8.10328	-7.91283	nan
20 MHz UNI PRF	2.816255	5.29876	12.34865	4.49672	7.241742	10.91619
10POS PPM 1.994 MHz NOM	6.189734	50.65183	565.3935	7.91672	17.04595	27.52351
10POS PPM 2 MHz NOM	10.53591	101.4635	654.8122	10.22672	20.0631	28.16117
2POS PPM 15.94MHz NOM	3.123719	6.921668	13.55226	4.94672	8.402108	11.32012
2POS PPM 15.91MHz NOM	0.636315	nan	nan	-1.96328	nan	nan
OOK (ser #3 UWB)	2.380521	2.069532	-0.76467	3.76672	3.158722	undefined
19.94 MHz 50% OF 2 MS	0.188223	0.21998	nan	-7.25328	-6.57616	nan
Gold 40 % (ser #3 UWB)	4.525557	153.3201	nan	6.55672	21.85599	nan
Gold (ser #3 UWB)	1.366696	0.893117	1.046609	1.35672	-0.49092	0.197844

Table 12. MAGR Position/Signal Strength Equivalency Factor Data

Waveform	Segment 1	Segment 2	Segment 3	Log Segment 1	Log Segment 2	Log Segment 3
1.0 MHz UNI PRF	No data	No data	No data	No data	No data	No data
1.994MHz UNI PRF	No data	No data	No data	No data	No data	No data
10 MHz UNI PRF	3.522775	3.266893	3.02695	5.468849	5.141349	4.810052
19.94 MHz 100%	2.104061	1.653174	1.980626	3.230584	2.183187	2.968025
20 MHz UNI PRF	2.772585	1.813518	2.464183	4.428849	2.585219	3.91673
10POS PPM 1.994 MHz NOM	3.588268	1.897501	4.938722	5.548849	2.781821	6.936146
10POS PPM 2 MHz NOM	3.20542	2.972589	4.161103	5.058849	4.731349	6.192084
2POS PPM 15.94MHz NOM	2.970879	1.219644	2.353277	4.728849	0.86233	3.71673
2POS PPM 15.91MHz NOM	1.806695	1.421498	1.950133	2.568849	1.527463	2.900642
OOK (ser #3 UWB)	5.493953	-0.48727	2.811934	7.398849	#NUM!	4.490052
19.94 MHz 50% OF 2 MS	1.421952	1.318666	1.845901	1.528849	1.201349	2.662084
Gold 40 % (ser #3 UWB)	2.593492	2.040546	nan	4.138849	3.097463	nan
Gold (ser #3 UWB)	2.311452	1.818638	2.494963	3.638849	2.597463	3.970642

Table 13. PLGR P-code PR Equivalency Factor Data

Waveform	Segment 1	Segment 2	Segment 3	Log Segment 1	Log Segment 2	Log Segment 3
1.0 MHz UNI PRF	11.23551	691.1109	nan	10.50593	28.39548	nan
1.994MHz UNI PRF	1.008466	51.931	nan	0.036614	17.15427	nan
10 MHz UNI PRF	1.008466	0.934687	-0.30471	0.036614	-0.29334	undefined
19.94 MHz 100%	0.637766	1.251881	8.045879	-1.95339	0.975631	9.055735
20 MHz UNI PRF	0.561903	0.692987	2.554829	-2.50339	-1.59275	4.073618
10POS PPM 1.994 MHz NOM	1.152554	16.43736	nan	0.616614	12.15832	nan
10POS PPM 2 MHz NOM	1.223662	52.71087	nan	0.876614	17.219	nan
2POS PPM 15.94MHz NOM	0.715585	0.882521	1.958873	-1.45339	-0.54275	2.920064
2POS PPM 15.91MHz NOM	0.819712	1.446357	6.442519	-0.86339	1.602755	8.090557
OOK (ser #3 UWB)	0.788245	0.847879	-0.35824	-1.03339	-0.71666	undefined
19.94 MHz 50% OF 2 MS	1.147259	9.011047	nan	0.596614	9.547753	nan
Gold 40 % (ser #3 UWB)	nan	nan	nan	nan	nan	nan
Gold (ser #3 UWB)	0.934677	0.866296	1.528955	-0.29339	-0.62334	1.843946

Table 1414. PLGR P-code PR Equivalency Factor Data

Waveform	Segment 1	Segment 2	Segment 3	Log Segment 1	Log Segment 2	Log Segment 3
1.0 MHz UNI PRF	No data	No data	No data	No data	No data	No data
1.994MHz UNI PRF	No data	No data	No data	No data	No data	No data
10 MHz UNI PRF	3.522775	3.266893	3.02695	5.468849	5.141349	4.810052
19.94 MHz 100%	2.104061	1.653174	1.980626	3.230584	2.183187	2.968025
20 MHz UNI PRF	2.772585	1.813518	2.464183	4.428849	2.585219	3.91673
10POS PPM 1.994 MHz NOM	3.588268	1.897501	4.938722	5.548849	2.781821	6.936146
10POS PPM 2 MHz NOM	3.20542	2.972589	4.161103	5.058849	4.731349	6.192084
2POS PPM 15.94MHz NOM	2.970879	1.219644	2.353277	4.728849	0.86233	3.71673
2POS PPM 15.91MHz NOM	1.806695	1.421498	1.950133	2.568849	1.527463	2.900642
OOK (ser #3 UWB)	5.493953	-0.48727	2.811934	7.398849	#NUM!	4.490052
19.94 MHz 50% OF 2 MS	1.421952	1.318666	1.845901	1.528849	1.201349	2.662084
Gold 40 % (ser #3 UWB)	2.593492	2.040546	nan	4.138849	3.097463	nan
Gold (ser #3 UWB)	2.311452	1.818638	2.494963	3.638849	2.597463	3.970642

SECTION 5 COMMUNICATION ANALYSIS

The tests and results described above establish the signal strength at which a UWB signal interferes with GPS operation. Holding UWB transmissions below that level places limitations on the maximum range over which UWB communications can occur and limitations on how close a UWB transmitter can be located to a GPS receiver. This section of the report addresses these issues.

5.1 INTERFERENCE ANALYSIS

The following assumptions were made in this analysis

- — Noise Temp Of GPS Receiver (PLGR) = TRx = 450° K
- — Sky Temp = TSky = 100° K
- — All Sources Of Interference Combined Are Allowed To Increase the GPS Noise Floor By 3 dB
- — UWB Interference Effect Approximated By The Effect of White Noise

This results in an interference threshold at the GPS antenna that must not be exceeded of

- — Interference = k(TSky + TRx) = -201.2 dBw/Hz
  or -141.2 dBm/KHz

This interference threshold is consistent with the RTCA allocation (-141.5 dBw/MHz) and with Rockwell Collins NetEx measurements, as discussed in previous sections of this report

Thus, -141.2 dBm/kHz is permitted at the GPS receiver for the sum of all broadband interference. The UWB allocation to this interference threshold is assumed to be -144.2 dBm/kHz, representing one-half of the total noise allocation (other broadband noise sources are expected to be present in addition to the UWB transmissions).

5.2 LINK BUDGET AND SUPPRESSION FACTOR

The scenario for calculating the link budgets is shown in Figure 22~~Figure 22~~. A UWB transmitter attempts to communicate with a UWB receiver at a distance Du. At the same time, it is desired that the UWB transmitter does not interfere with a GPS receiver co-located at a distance Dg.

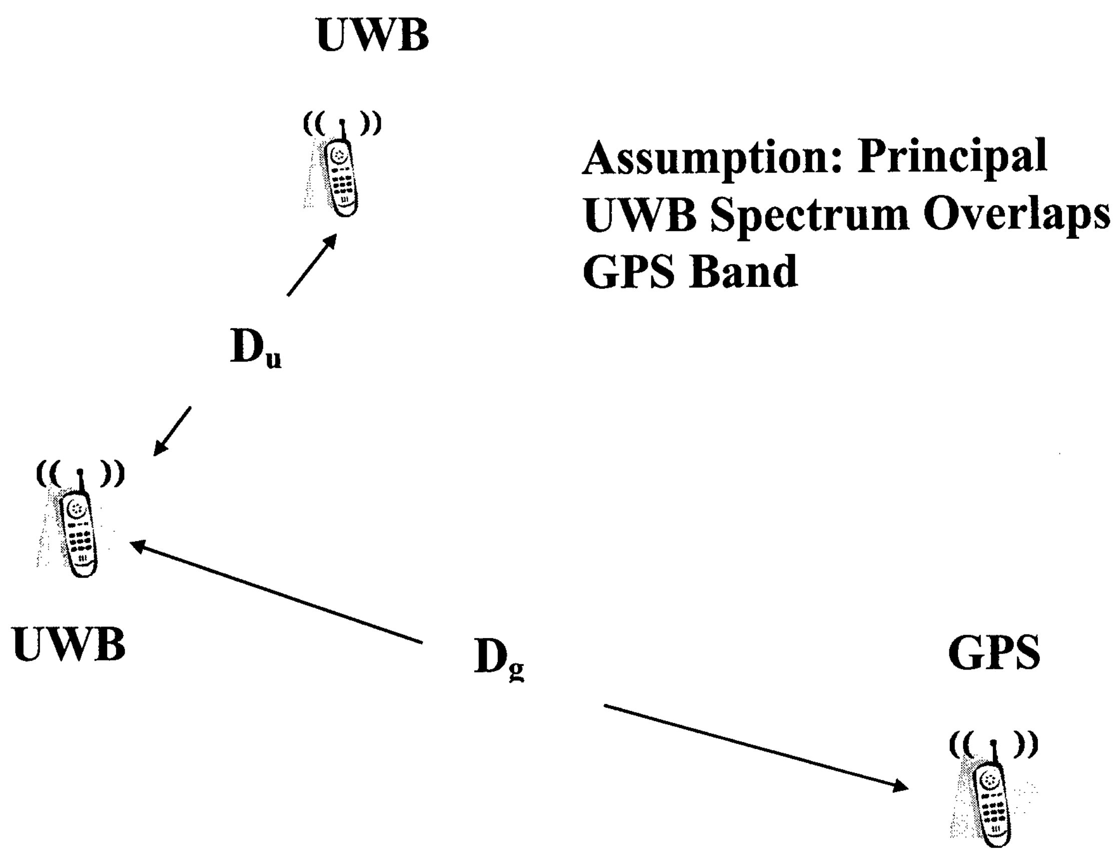


Figure ~~22~~22. Communications and Interference Scenario

A general link budget is given by

S/N = Pt + Gt - Lt – L + Gr - Lr – Pn

Pn = -174 + Nf + 10 Log(BW)

Where

S/N is the received signal to noise ratio
Pt is the transmit power
Gt, Gr, Lt, Lr are the transmit and receive antenna gains and system losses
L is the propagation loss
Pn is the received noise level
Nf is the receiver noise figure
BW is the receiver bandwidth

The propagation losses are assumed to be free-space or plane earth depending on the link distance. For the antenna heights used herein, the break point is about 200 meters where free space propagation holds for less than 200 meters and plane earth propagation holds above 200 meters.

Free space Propagation Loss is

L = (- 28 + 20 Log F + 20 Log D)

Plane Earth Propagation Loss is

$$L = (40 \text{ Log } D - 20 \text{ Log } HtHr)$$

Further assumptions regarding the link are:

-EMI to GPS Receiver is determined by the average UWB Power in the RX passband

-UWB RX BW is matched to the UWB pulse width

The allowable noise density threshold at the victim GPS receiver, which must be -144.2 dBm/Hz or less, is

$Ng = Nt + Gt - Lt - Li - Si + Gg - Lg$, where

Nt = Transmitted UWB noise density

Gt, Lt, Gg, Lg are antenna gains and system losses

Li = Propagation loss from UWB Tx to GPS Rx

and Si = An additional suppression factor applied to the transmitted UWB signal by filtering, frequency separation of the UWB signal from the GPS signal, or any other means.

This results in an allowable noise density of the UWB transmitter of

$$Nt = Ng - Gt + Lt + Li + Si - Gg + Lg$$

The total transmit power at UWB transmitter with bandwidth BW is

$$\begin{aligned} Pt &= Nt + 10 \text{ Log}(BW) \\ &= Ng - Gt + Lt + Li + Si - Gg + Lg + 10\text{Log}(BW) \end{aligned}$$

In order to avoid interference at the GPS receiver, the UWB transmit power must be limited to this amount or less. This determines the Signal to Noise ratio at the UWB receiver with propagation loss Lu to

$$S/N = Pt + Gt - Lt - Lu + Gr - Lr - (-174 + Nf + 10 \text{ Log}(BW))$$

Using Pt from the UWB-GPS interference link budget gives

$$\begin{aligned} S/N = {} & Ng - Gt + Lt + Li + Si - Gg + Lg + 10\text{Log}(Bw) \\ & + Gt - Lt - Lu + Gr - Lr \\ & - (-174 + Nf + 10 \text{ Log}(BW)) \end{aligned}$$

This can be solved to determine suppression factor needed to avoid interference to the GPS receiver while providing the required signal to noise ratio at the UWB receiver. This is

$$\begin{aligned} Si = {} & - Ng + Gt - Lt - Li + Gg - Lg - 10\text{Log}(Bw) \\ & - Gt + Lt + Lu - Gr + Lr \\ & - 174 + Nf + 10 \text{ Log}(BW) + S/N \\ = {} & - Ng - 174 + Lu - Li + Nf + S/N \\ & + Gg - Lg - Gr + Lr \end{aligned}$$

For UWB-GPS separation distances, Dg, of interest (less than 200 meters) the propagation loss is free space so

$$Si = -Ng - 174 + Lu - (-28 + 20 \text{ Log}(F) + 20 \text{ Log}(Dg)) + Nf + S/N$$
$$+ Gg - Lg - Gr + Lr$$

For short UWB communications ranges (less than 200 meters), Du, the propagation loss is also free space, giving

$$Si = -Ng - 174 + (-28 + 20 \text{ Log}(F) + 20 \text{ Log}(Du)) -$$
$$(-28 + 10 \text{ Log}(F) + 10 \text{ Log}(Dg)) + Nf + S/N$$
$$+ Gg - Lg - Gr + Lr$$
$$= -Ng - 174 + 20 \text{ Log}(Du) - 20 \text{ Log}(Dg) + Nf + S/N$$
$$+ Gg - Lg - Gr + Lr$$

For larger distances where propagation is plane earth, yielding

$$Si = -Ng - 174 + Nf + S/N$$
$$+(40 \text{ Log}(Du) - 20 \text{ Log}(HtHr))$$
$$- (-28 + 20 \text{ Log}(F) + 20 \text{ Log}(Dg))$$
$$+ Gg - Lg - Gr + Lr$$

An example of this analysis for a short range, high data rate UWB-UWB link is shown below. The UWB-UWB link parameters were.

- Data Rate 10 Mbps
- Pulse Width = 1 Nanosecond
- Center Frequency = 1575 MHz
- Bandwidth = 1 GHz
- Antenna Gain = 2 dB
- Antenna Height = 2 Meters
- System Loss = 1 dB
- Noise Figure = 1 dB
- Required S/N = 10 dB

The UWB-GPS link parameters were

- Interference threshold = -144.2 dBm/kHz
- GPS Antenna Gain in direction of UWB = 0 dB
- Separation distances of 1m, 10m, 100m

Figure 23~~Figure 23~~ shows the maximum permissible transmit power for the UWB transmitter in dBm to avoid interference to the GPS receiver. The x-axis is the log of the distance between the UWB transmitter and GPS receiver (e.g. x value of 1 is 10 meter separation between the UWB transmitter and GPS receiver). For example, for a 10 meter UWB-GPS separation the maximum UWB transmitter power is about -25 dBm measured in the transmitter's 1 GHz bandwidth assuming R^2 propagation. Note, in both Figure 23~~Figure 23~~ and Figure 24~~Figure 24~~, R^2 propagation should be used for distances less than about 200 meters and plane earth should be used for distances above 200 meters.

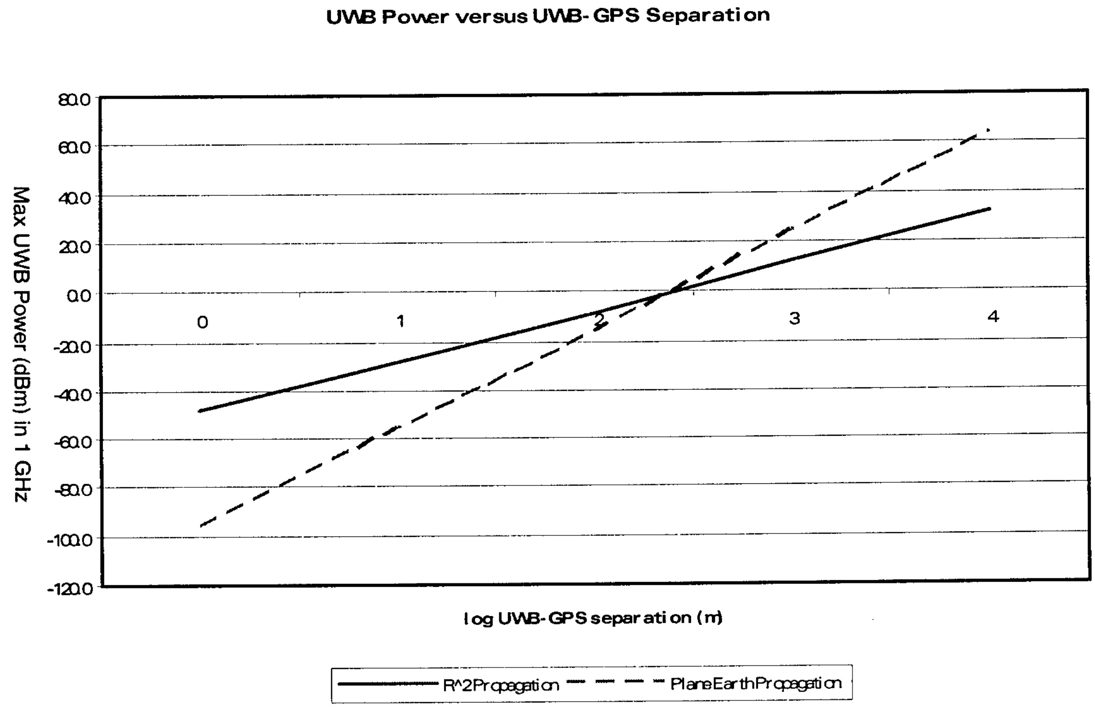


Figure 23~~23~~. Allowable UWB Transmission power

The results of Figure 23~~Figure 23~~ can be translated into achievable communications distances using the assumed UWB receiver parameters as shown in Figure 24~~Figure 24~~. This shows the log of the achievable communications range as a function of the log of the UWB-GPS separation distance. For example for a UWB-GPS separation of 10 meters (log value of 1) the achievable communications range is about 3 meters (log value of 0.5) assuming an R^2 communications-link propagation model. The results shown in Figure 23~~Figure 23~~ and Figure 24~~Figure 24~~ are based on the UWB signal spectrum overlapping the GPS signal so that the GPS receiver has no protection against the UWB interference. If the UWB signal spectrum falling into the GPS band is suppressed, then communications range can be increased with interfering with the GPS reception. The suppression can be by any means, for example notch filtering the UWB signal before transmitting it or using a band other than GPS for the UWB transmission. In the latter case the suppression factor can be viewed as how much the residual UWB signal occupying the GPS frequency is down from its value at the UWB "center" frequency.

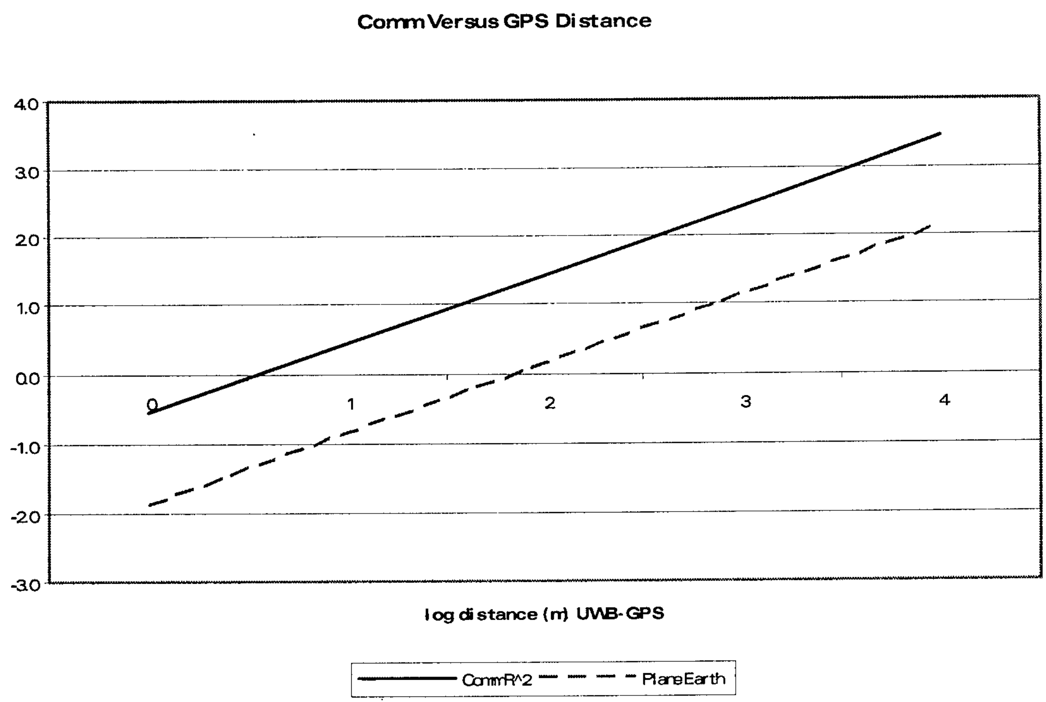


Figure 24~~24~~. Communications Range as a Function of UWB-to-GPS Separation Distance

Figure 25~~Figure 25~~ shows the required suppression factor to achieve a given communication range for several representative UWB-GPS separation distances. For example, for a UWB-GPS separation of 1 meter (top curve), achieving a communication range of 200 meters (log value of 2), the UWB signal spectrum falling in the GPS band must be suppressed by about 55 dB. Moving the GPS receiver 10 meters from the UWB transmitter reduces the suppression factor to 35 dB.

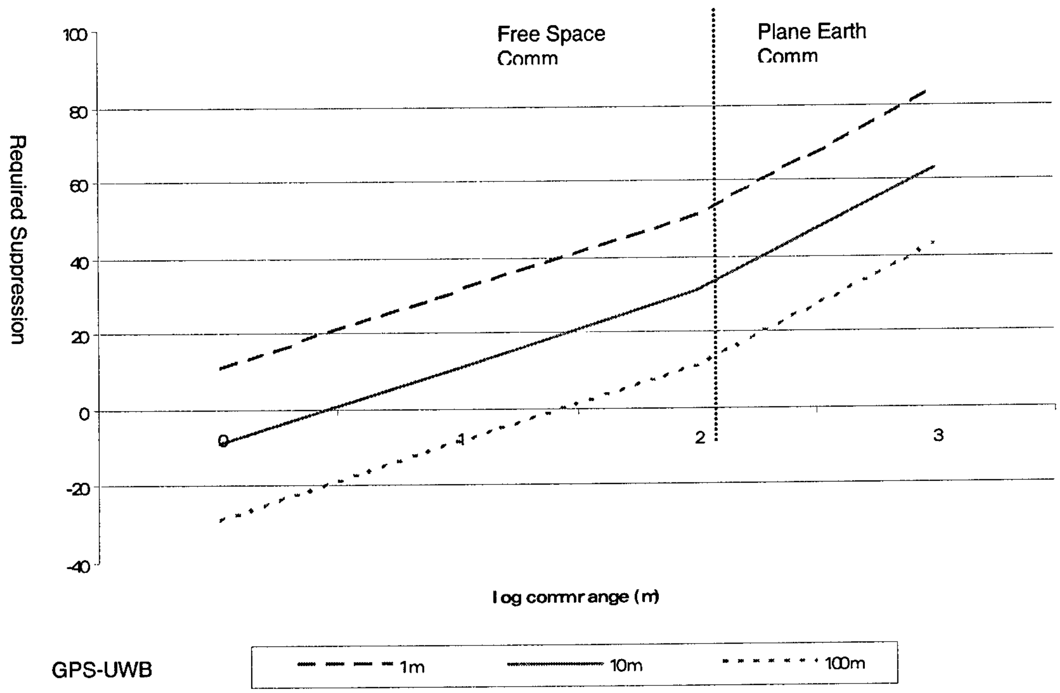


Figure 25~~25~~. Required Suppression Factor as a Function of Desired Communications Range.

5.3 OUTAGE PROBABILITY

The GPS suscepability measurements presented herein establish how much UWB signal is required to interfere with GPS operation but they do not address how often the UWB energy is at or above that level. Figure 26~~Figure 26~~ shows a scenario used to estimate the percent of time that, for a given threshold UWB signal level at the GPS receiver (-144.2 dBm/Hz was used in the preceding analysis), how often the UWB signal level exceeds that threshold. The percent of time the composite UWB signal level exceeds that threshold establishes the percent of time the GPS operation is unacceptable or, in other words, the outage probability.

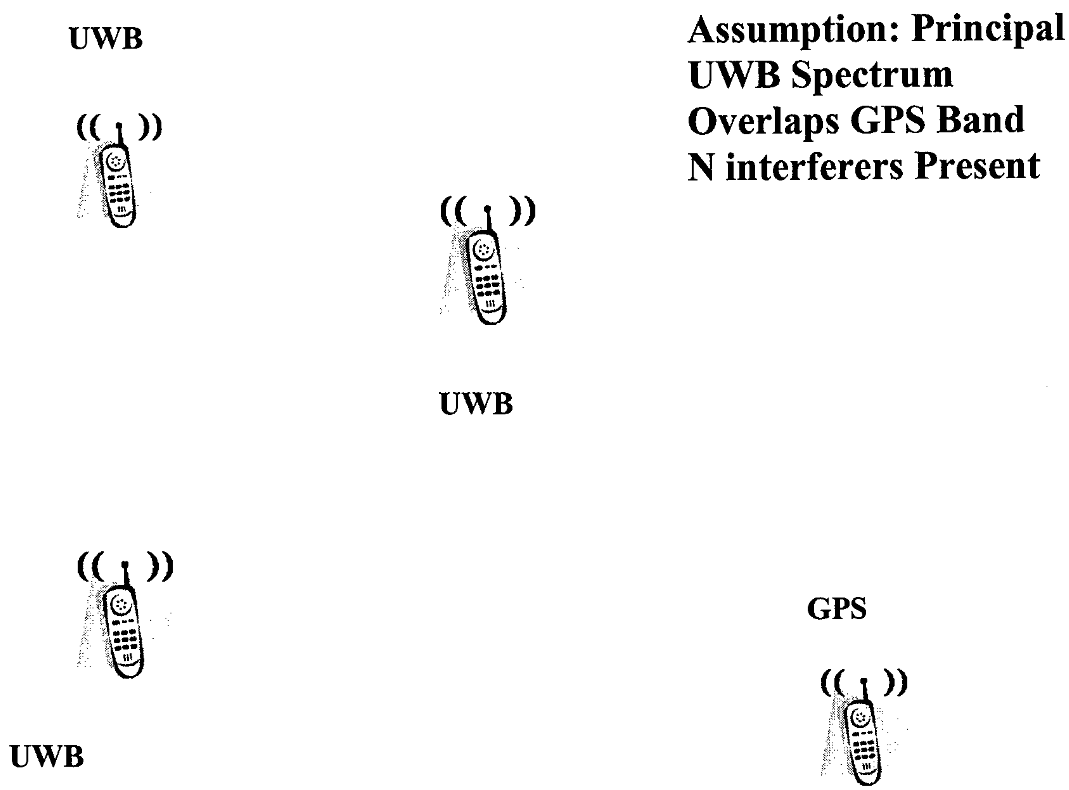


Figure 26~~26~~. Scenario of N interferers overlapping GPS receiver band.

The composite UWB signal is given by the sum of N UWB transmitters, randomly located around the GPS receiver.

The received Signal r(t) at the GPS is given by,

$$r(t) = s(t) + \eta(t) + \sum_{n=1}^{N} I_n(t)$$

Where s(t) denotes desired GPS signal,
η(t) denotes noise,
In(t) denotes the nth interference function

Let $$I(t) = \sum_{n=1}^{N} I_n(t)$$

Assume a terrestrial environment wherein I(t) is Rayleigh distributed

Then

$$p(W_I) = (1/W_o)Exp(-W_I/W_o)$$

Where WI Denotes the random interference power and Wo the mean of WI

A GPS outage will occur whenever the random variable WI exceeds The -141.2dBm/KHz threshold determined previously (Let α denote this threshold)

Let the outage probability be set not to exceed 10^{-6}.
Then

$$10^{-6} = \int_{10^{\alpha/10}}^{\infty} p(W_I)dW_I = Exp(-10^{\alpha/10}/W_o)$$

or

$$W_o = -10^{\alpha/10}/Ln(10^{-6})$$

i.e. Wo = α -10Log10 (-Ln(10-6)) = -152.6 dBm/kHz

With -141.2 dBm/KHz as a GPS total interference threshold, the sum of all UWB interference must be less than -152.6 dBm/KHz to yield a GPS outage probability not exceeding 10^{-6}.

The threshold of UWB received level of -144.2 dBm/KHz, used in the analysis above results in an outage probability of 0.15

5.4 CONCLUSION

If the UWB principal spectrum overlaps the GPS frequency band

- — Unacceptable degradation to GPS operation occurs unless the communication range is limited in this example to less than the minimum separation of the UWB transmitter and GPS receiver

If the UWB principal spectrum does not overlap the GPS frequency band

- — The maximum acceptable level of residual emission falling within the GPS can be calculated and the level of suppression relative the UWB principal power spectrum can be quantified.

This was a fairly high data rate example.

- — Lowering the data rate would reduce the required suppression by a factor of approximately 10 Log(data rate reduction).

This analysis assumed UWB waveforms impact GPS performance the same as an equal amount of AWGN

- — UWB waveforms with noise equivalence factors greater than 1 (0dB) reduce the required suppression dB for dB

— Noise equivalence factors less than 1 increase the required suppression dB for dB

Setting UWB emissions thresholds near the level measured to cause interference to GPS in the laboratory may result unacceptable outage probabilities in practice. This is due to the random fluctuations in signal level when several UWB emitters, each within the prescribed threshold, are in close proximity to the GPS receiver.

SECTION 6 ANTENNA STUDY

6.1 APPROACH AND METHOD

The objective of the antenna study was to evaluate the PLGR radiated antenna frequency response over a very wide bandwidth in order to determine the potential impact of UWB waveforms on the PLGR front end. The PLGR uses a helix antenna. The approach taken was to measure the antenna response over a 12 GHz frequency range and take the inverse FFT of the frequency data to evaluate the temporal impulse response.

The antenna frequency response test setup is shown in Figure 27~~Figure 27~~. The method used was to measure the PLGR helix radiated response in an anechoic chamber. Two 0.7 to 18 GHz double-ridge horn antennas were used to first establish the calibrated radiated path reference. Then one of the horn antennas was replaced with the PLGR helix. The radiated gain pattern was measured for two orientations over 0.7 to 12 GHz. The Normal orientation, as illustrated in Figure 27~~Figure 27~~, has the horn antenna ninety degrees off the helix boresight. The Axial mode had the horn antenna pointing directly at the top of the helix antenna directly along the antenna boresight.

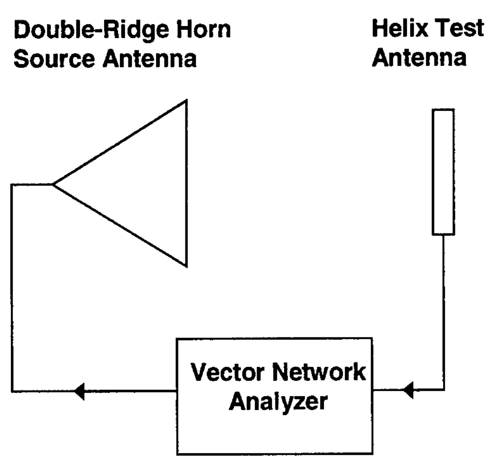


Figure 27~~27~~. PLGR helix antenna test setup.

The resulting frequency response graphs for both antenna orientations are given in Figure 28~~Figure 28~~. Note that at GPS L1 and L2 (1575.42 MHz and 1227.6 MHz) the PLGR antenna provides decent gain as well as appreciable selectivity to near, out-of-band frequencies. However, for frequencies above 2.3 GHz the selectivity of the antenna is greatly reduced as the gain as a function of frequency passes through many maxima and minima. The gain response for the Axial mode is particularly strong from about 6 to 8 GHz and again at just over 11 GHz. The normal mode has better gain behavior, but selectivity is also significantly reduced over the range of 2.3 to 12 GHz.

The time response for the Normal mode frequency response was computed and this is shown in Figure 29~~Figure 29~~. The strong impulsive components evident in this impulse response have the potential to interact with UWB waveform components to cause interesting and possibly unexpected effects on the PLGR front end circuitry. More study

is necessary to determine how harmful these effects might be for military applications where P-code tracking and C/A-code acquisition are used.

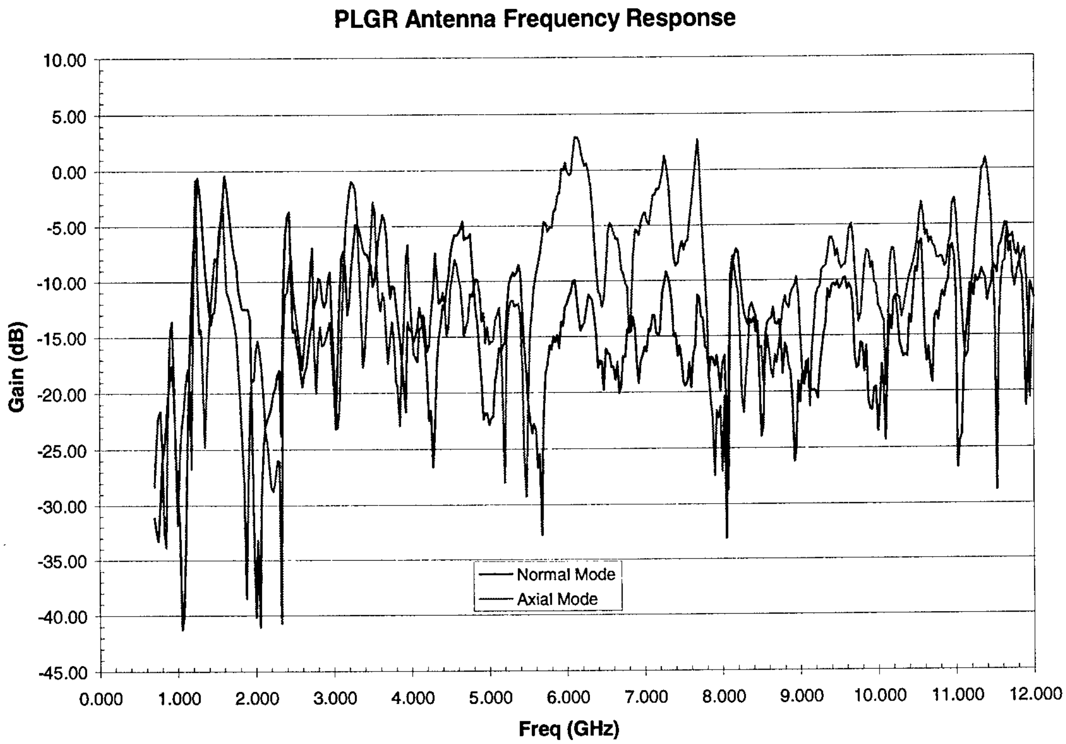


Figure 28~~28~~. Frequency Response plots for the PLGR helix antenna, Normal and Axial modes.

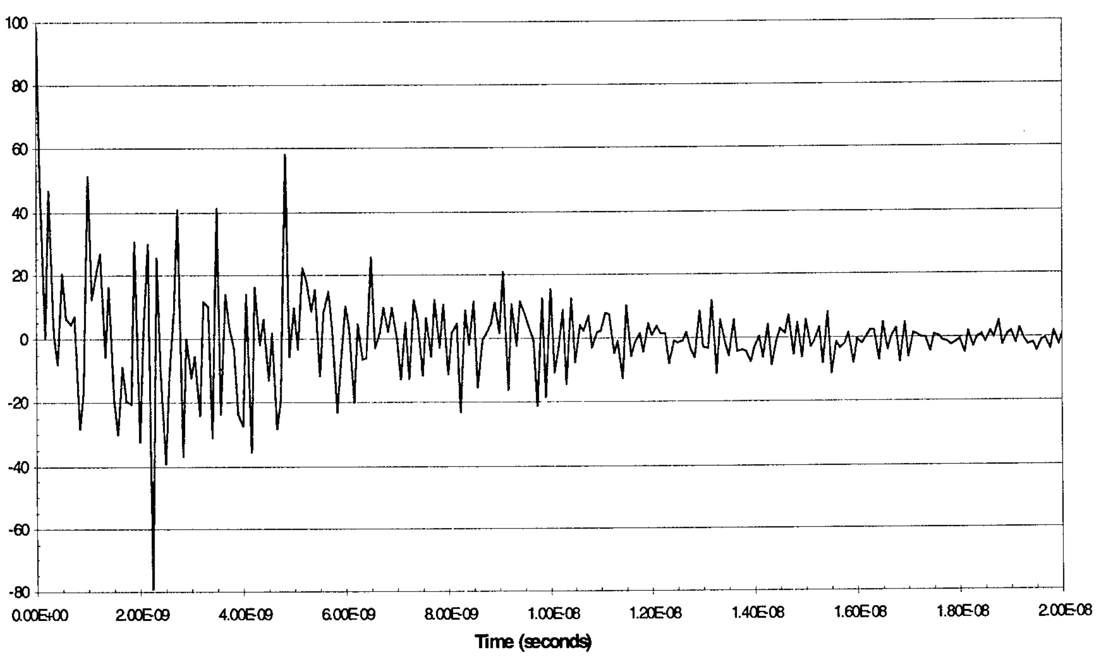


Figure 29~~29~~. Time response for the PLGR helix Normal mode gain response.

6.2 ANTENNA STUDY CONCLUSIONS

By measuring the PLGR helix antenna radiated frequency response in a calibrated environment it was determined that the PLGR antenna's gain response provides little attenuation for far out-of-band RFI for both Normal and Axial modes. The Axial mode response was significantly worse than the Normal mode gain response especially in certain frequency ranges. Hence, the PLGR's front end filtering needs to maintain good rejection for far out-of-band RFI components, such as might be emitted by UWB transmitters. The degree of front end rejection needed requires further study to quantify.

ACRONYM LIST

- A -

ARB	Arbitrary Waveform Generator
AWG	Arbitrary Waveform Generator

-B-

BW	Bandwidth

-C-

CW	Continuous Wave

-D-

dB	Decibel
dBm	Decibel in relation to a milli-Watt

-E-

E3	Electromagnetic Environmental Effects
EMI	Electromagnetic Interference

-F-

-G-

GHz	Gigahertz

-H-

Hz	Hertz

-I-

-J-

-K-

KHz	Kilohertz

-L-

-M-

MHz	Megahertz
Mpps	100 Million pulses per second

-N-

NAS	Naval Air Station
NAWC AD	Naval Air Warfare Center, Aircraft Division
NETEX	Networking in Extreme Environments

-O-

-P-

PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
PRR	Pulse Repetition Rates
PPM	Pulses Per Minute
PW	Pulse Width

-Q-

-R-

RF	Radio Frequency

-S-

-T-

-U-

UWB	Ultra-Wide Band

-V-

-W-

-X-

-Y-

-Z-

APPENDIX A UWB RF SPECTRAL OUTPUT

The spectral composition of the UWB RF output under various waveform excitations are documented below. The UWB output was passed through a bandpass filter to allow more detailed inspection of the frequencies of interest around GPS L1, 1575.4 MHz. These plots were used to calculate the UWB power delivered to the GPS receiver front end.

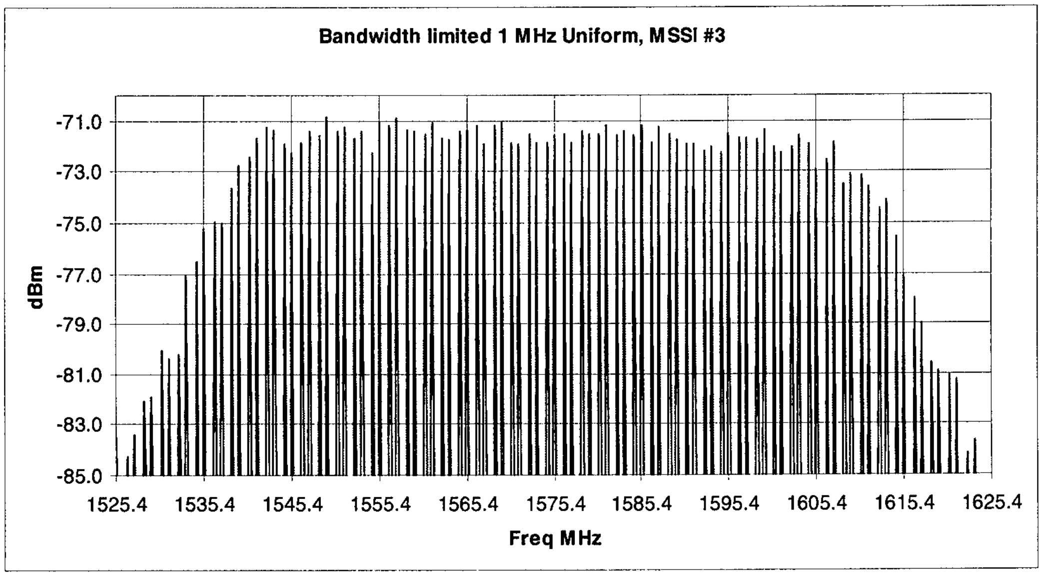


Figure 30~~30~~. UWB RF Spectral Output with 1 MHz Uniform PRF Waveform

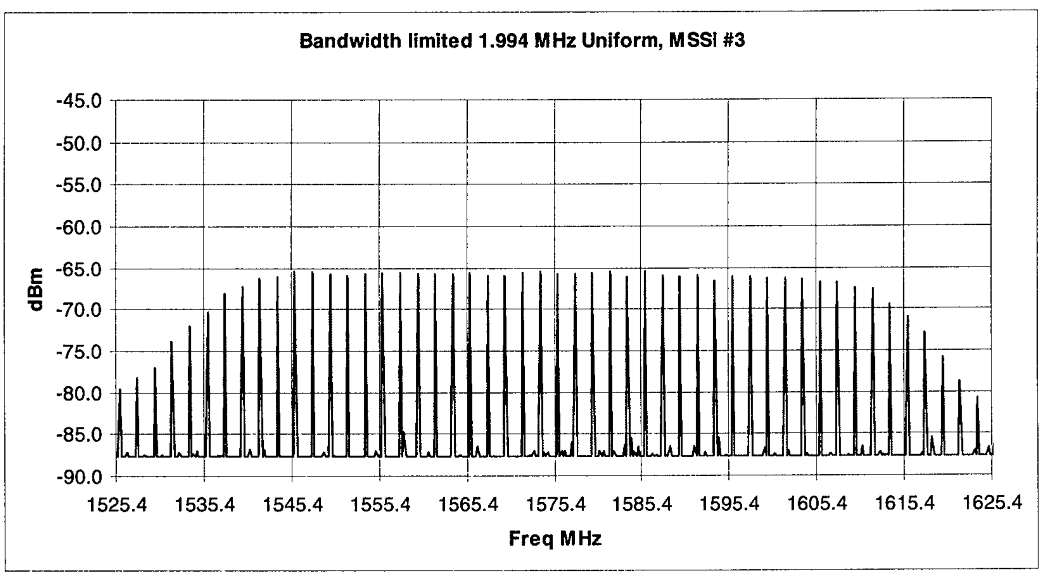


Figure 31~~31~~. UWB RF Output with 1.994 MHz Uniform PRF Waveform

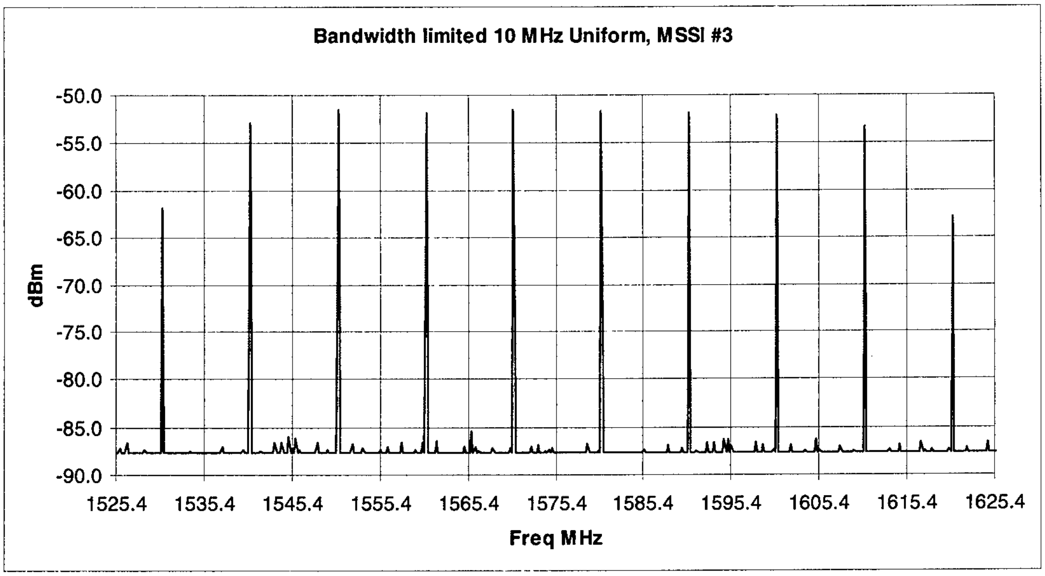


Figure 32~~32~~. UWB RF Spectral Output with 10 MHz Uniform PRF Waveform

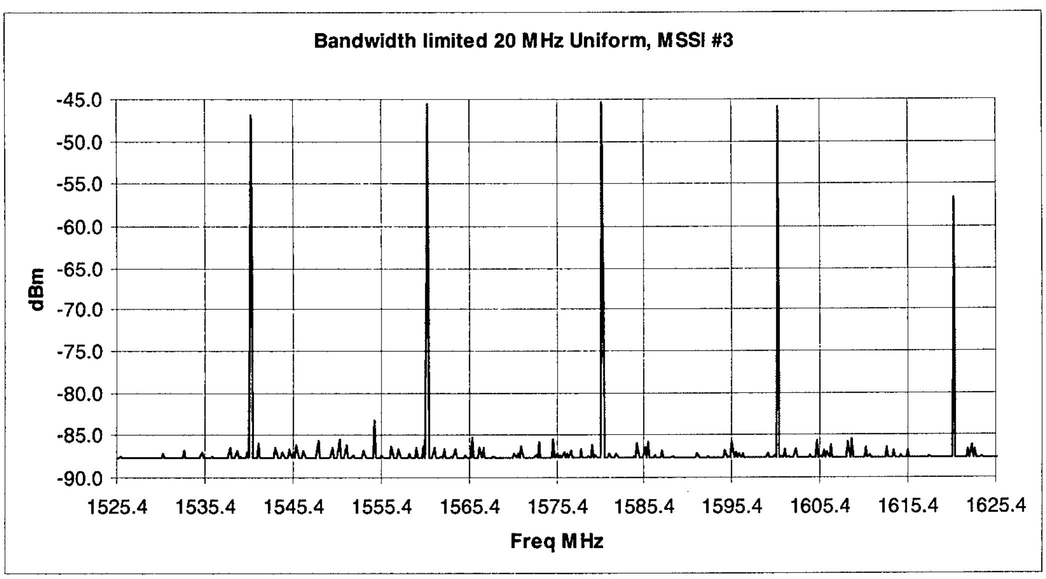


Figure 33~~33~~. UWB RF Spectral Output with 20 MHz Uniform PRF Waveform

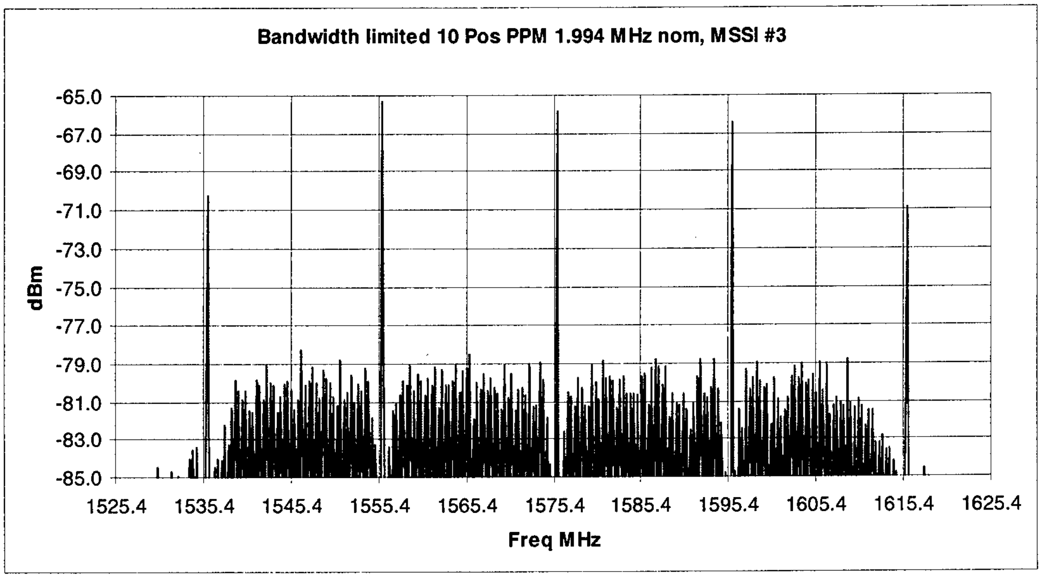


Figure 34~~34~~. UWB RF Spectral Output with 10 position Pulse Position Modulation, 1.994 MHz nominal PRF Waveform

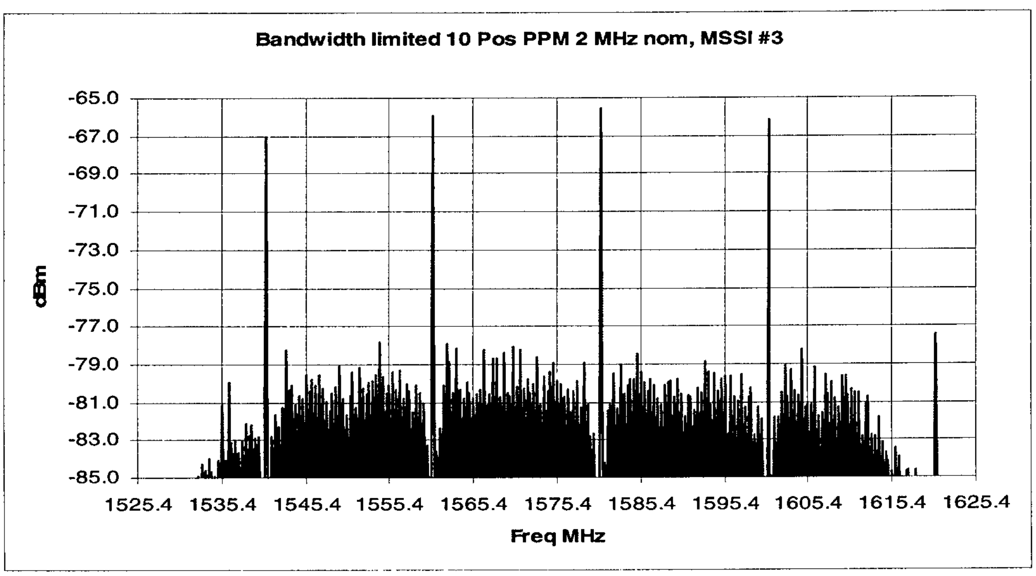


Figure 35~~35~~. UWB RF Spectral Output with 10 position Pulse Position Modulation, 2 MHz nominal PRF Waveform

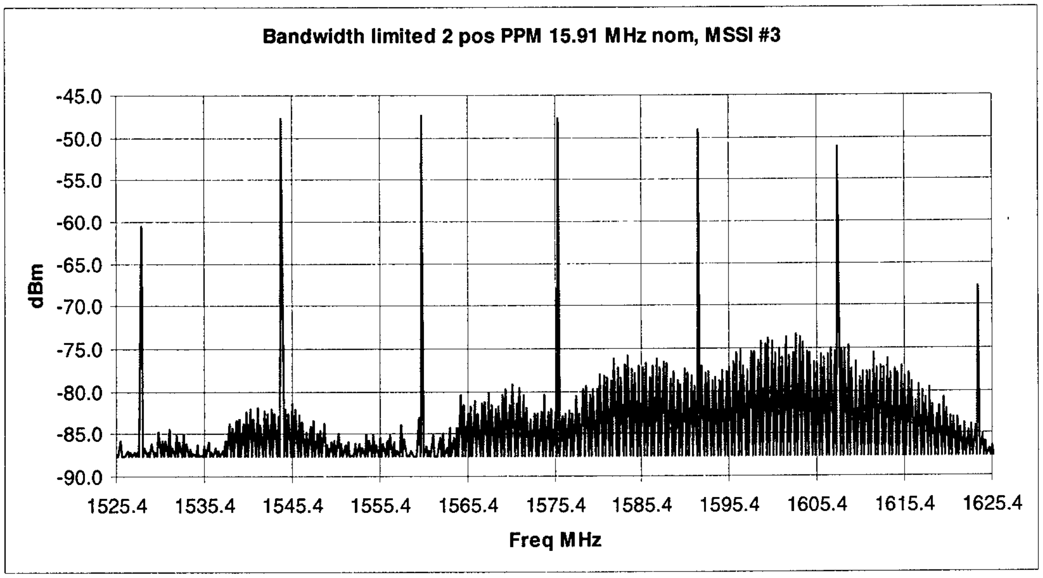


Figure 36~~36~~. UWB RF Spectral Output with 2 position Pulse Position Modulation, 15.91 MHz nominal PRF Waveform

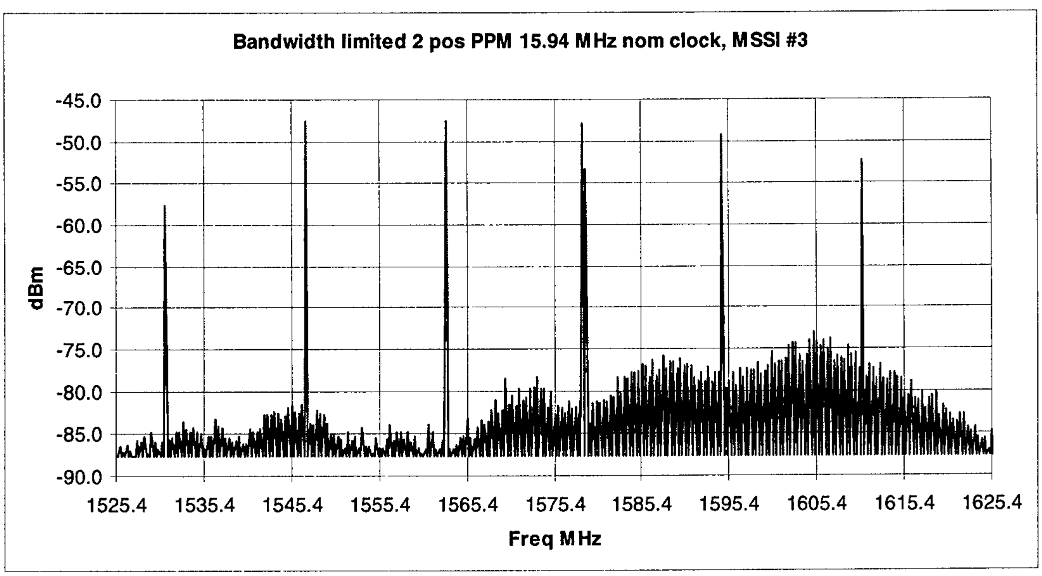


Figure 37~~37~~. UWB RF Spectral Output with 2 position Pulse Position Modulation, 15.94 MHz nominal PRF Waveform

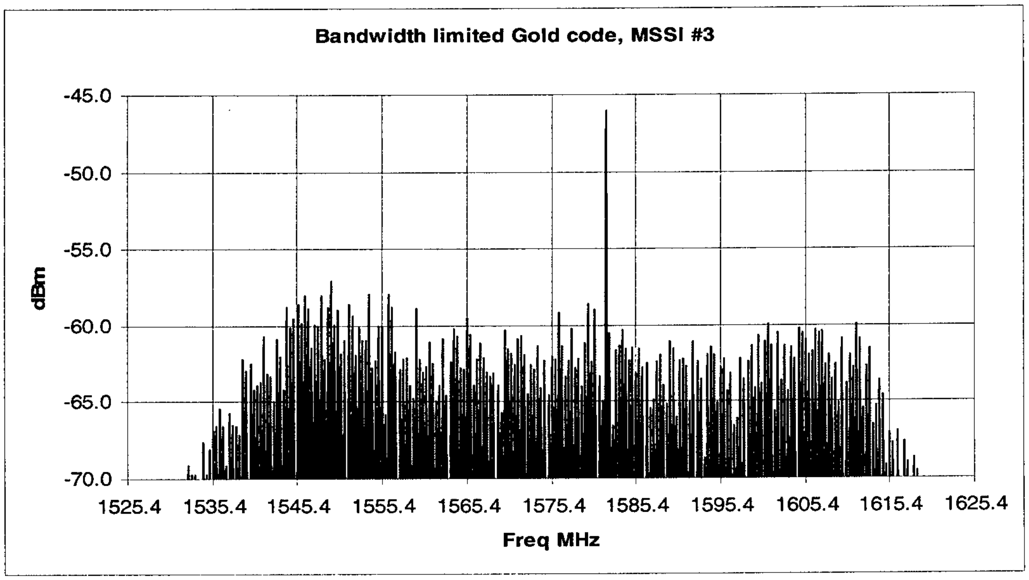


Figure ~~38~~38. UWB RF Spectral Output with Gold Communication Waveform

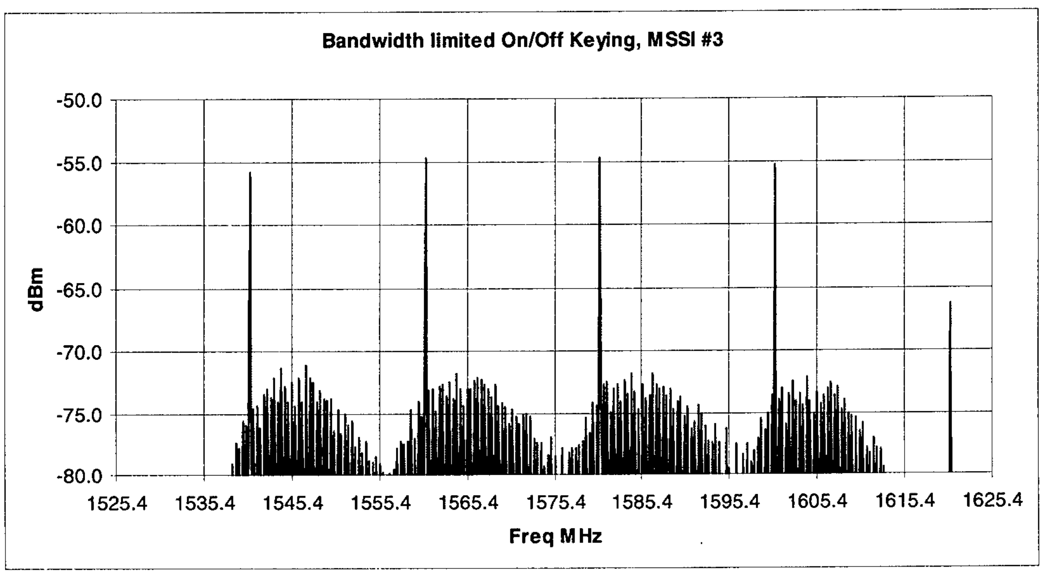


Figure 39~~39~~. UWB RF Spectral Output with Pseudorandom On/Off Keying at 200 MHz

APPENDIX B UWB POWER DETERMINATION

The UWB power was measured with a high sensitivity power meter for each waveform. The measurement was through an 80 MHz bandpass filter and a low pass. The filters had a 10 dB of attenuation in line to insure proper termination of the filters.

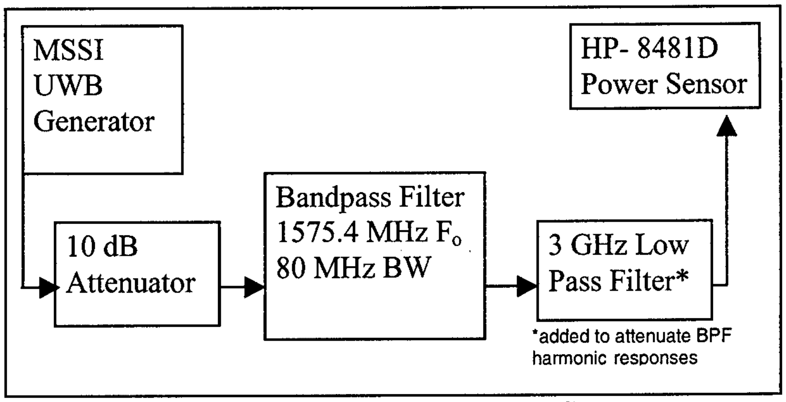


Figure 40~~40~~. UBW Power Measurement Setup

The UWB RF spectral output data was recorded by replacing the Power Sensor with a Spectrum Analyzer. The UWB RF spectral output data is documented in Appendix A for each waveform.

The measured power for each waveform was recorded in the 80 MHz bandwidth. The filters and attenuator are not used during the UWB interference testing, so the measurements are corrected for the loss through the filters and the attenuator. The GPS has a 20 MHz bandpass filter designed into the receiver RF front end. The UWB power that is presented to the receiver is adjusted to reflect the power to the GPS receiver front end. For the UWB waveforms that have dense closely spaced frequency components, the power adjustment for the bandwidth change from 80 MHz to 20 MHz is a simple ratio, so the measured power is reduced 6 dB. An example of this type of UWB spectral output is shown in Figure 41~~Figure 41~~.

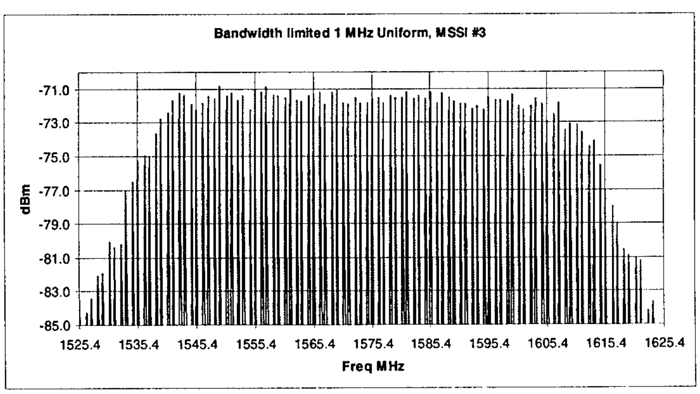


Figure 41~~41~~. UWB RF Output that Allows 6 dB BW Adjustment

The RF spectral output of certain UWB waveforms contain distinct, discrete frequencies components. An example of a UWB RF spectral output containing a discrete frequency component is shown in Figure 42~~Figure 42~~.

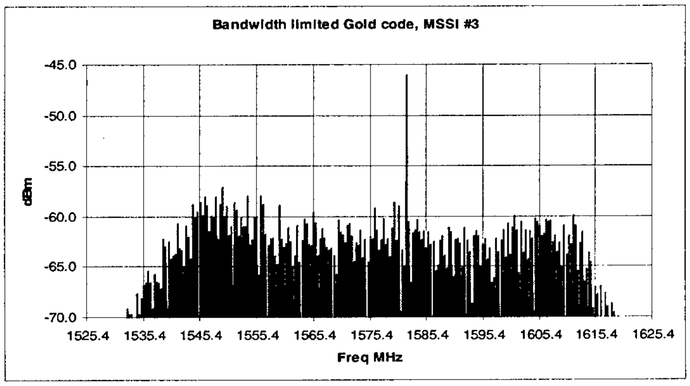


Figure 42~~42~~. UWB RF Output with Discrete Frequency Component

The procedure to determine the power presented to the GPS front end from a UWB waveform that had discrete spectral components is to subtract the power contained in the discrete components. The 80 to 20 MHz bandwidth conversion is made to the remaining power by subtracting 6 dB. The power for the discretes that fall only in the 20 MHz bandwidth around 1575.4 MHz (GPS L1 front end frequency) is added back into the bandwidth reduced power.

For the UWB waveform in Figure 42~~Figure 42~~, the measured power in the 80 MHz bandwidth was -27.6 dBm after the filter losses had been factored out. The spectrum contains a single discrete at -44 dBm in the 20 MHz GPS front end passband. The power of the discrete is removed.
-27.6 dBm = 1.74×10^{-3} Watts   -44 dBm = 39.6×10^{-6} Watts
Power in 80 MHz without discrete is 1.74 – 0.04 = 1.7 milliWatts = -27.7 dBm
To convert to 20 MHz BW, subtract 6 dB. Power in 20 MHz BW with no discretes is -33.7 dBm
Add back in the power of the discrete that falls within the 20 MHz bandwidth. -33.7 dBm = 427 microWatts plus 39.6 microWatts for the discrete power.

For the UWB spectral output shown in Figure 42~~Figure 42~~, the total power in the 20 MHz bandwidth containing the single discrete is -33.3 dBm.

A second example is shown below for a UWB spectrum with discretes spread over the 80 MHz bandwidth. All discrete power is subtracted out before the 6 dB bandwitdth adjustment is performed. Only the discretes in the 20 MHz BW around GPS L1 frequency are added back into the presented power

For the UWB spectrum shown in Figure 43~~Figure 43~~, with filter losses removed, 80 MHz BW power measured -43.7 dBm (42.7 uW)
One In-band discrete is at -66 dBm (0.25 uW)
4 Out of Band discrete are at -65, -66, -70 & -71 dBm, (0.31, .25, .1 & .08 uW)
80 M power less power in all of the discretes = 42.7 -1 uW = 41.7 uW (43.8 dBm)
20 M BW power with no discretes = -43.8 dBm less 6 dB = -49.8 dBm (10.5 uW)
Power seen by GPS Receiver is 20 MHz BW power plus the power in the In-band discrete= 10.5 + .25 = 10.7 uW =-49.7 dBm

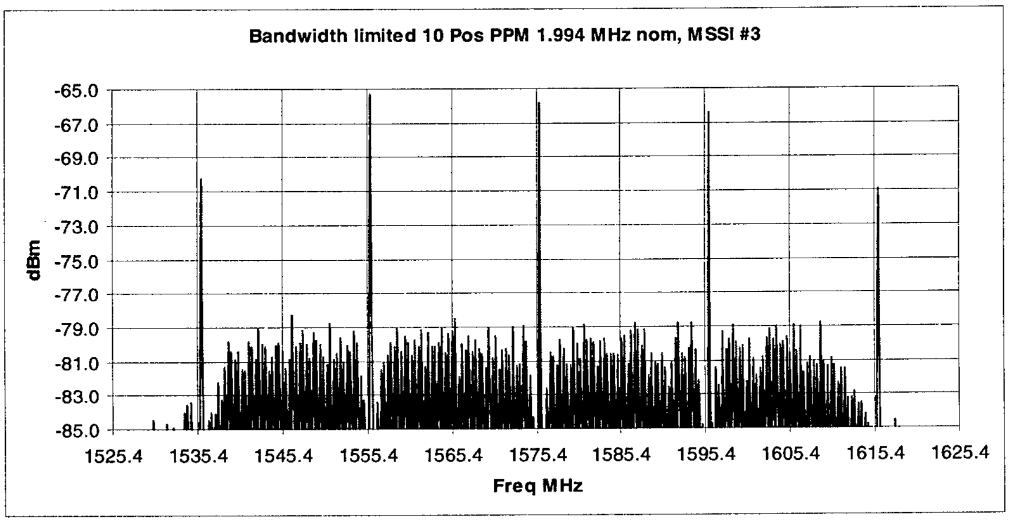


Figure 43~~43~~. UWB RF Spectrum with Distributed Discrete Components

Contract # N00421-02-C-0005

Final Submission

APPENDIX C
UWB EMI TEST PLAN FOR THE AN/PSN-11
PRECISION LIGHTWEIGHT GPS RECEIVER (PLGR)

July 11, 2003

APPENDIX C
UWB EMI TEST PLAN FOR THE AN/PSN-11 PRECISION LIGHTWEIGHT GPS RECEIVER (PLGR)

1.0 INTRODUCTION

The AN/PSN-11 is the Precision Lightweight GPS Receiver (PLGR). The PLGR is a 5-channel P-Code L1 GPS portable handheld/vehicular receiver designed for land warrior navigation.

The AN/PSN-11 PLGR has operational frequencies of 1575.42 MHz (L1) and 1227.6 MHz (L2). The standard responses are 3-D position and velocity. The GPS signal modulation is pseudo-random BPSK at 10.23 MHz (P-code), 1.023 (C/A-code) MHz rates. The GPS signal also contains a 50 bps BPSK satellite ephemeris data overlay. The IF Bandwidth is 25 MHz (nominal). The sensitivity is sufficient to acquire and track GPS SPS and PPS signals at -130 to -136 dBm.

2.0 OVERALL TEST OBJECTIVE

The overall objective of the test is to determine the RFI susceptibility of the primary operational modes of the PLGR to conducted UWB signals that are injected into the receiver auxiliary antenna port. The results of this investigation will provide the information necessary to evaluate the potential for UWB signals to interfere with the PLGR and to understand how UWB systems could be implemented to make use of their unique capabilities without causing EMI.

3.0 TEST APPROACH

In order to accomplish the test objective, there are several performance metrics that must be measured, each of which corresponds to a major operational mode of the receiver. These metrics are the P-code tracking pseudorange (PR) standard deviation and the position accuracy and/or signal strength susceptibility for steady-state P-code tracking. For each metric, an interference substitution approach will be used to collect the relevant test data.

Only L1 susceptibility testing will be performed. The performance impact to L2 would be equivalent when differences in satellite power levels and in-band interference components are accounted for.

4.0 INTERFERENCE SUBSTITUTION TEST METHODOLOGY

The interference substitution test method is illustrated in Figure 1. The method for NETEX military GPS receiver testing is adapted from one developed by RTCA SC-159

for use in the civil aviation GPS receiver tests with UWB RFI. It first establishes the baseline receiver performance against a standard interference source (e.g., broadband noise in Fig. 1), then known portions of the standard interference power are removed and replaced by measured amounts of UWB interference to give the same receiver performance. Comparison of the amounts of UWB power added with the amounts of standard RFI source power removed yield a power equivalence factor for the particular UWB waveform in the test in terms of equal RFI effect with the standard RFI source. This equivalence factor is useful in subsequent scenario analysis and receiver effect diagnosis.

The standard RFI source for the PR testing is broadband noise in similarity to the previous interference tests that were performed on commercial aviation grade GPS receivers.

The standard RFI source for the position error/signal strength testing is narrowband interference, i.e., a CW tone at a fixed frequency in the GPS passband, in similarity to legacy PLGR, conducted susceptibility tests. A broadband noise interference signal is also used, again in similarity to legacy conducted susceptibility tests, but this noise level will remain fixed during the test and will not be considered part of the standard RFI source against which the UWB interference is compared.

For consistency with the NETEX RFI tests on other receivers, an additional test condition is used. In that case, no standard RFI source power is injected and the UWB power for the i^{th} mode (Uix) is determined which causes the full RFI effect (red curve in Fig. 1). For completeness, the underlying base receiver noise (Nrx) added to the UWB power is also determined.

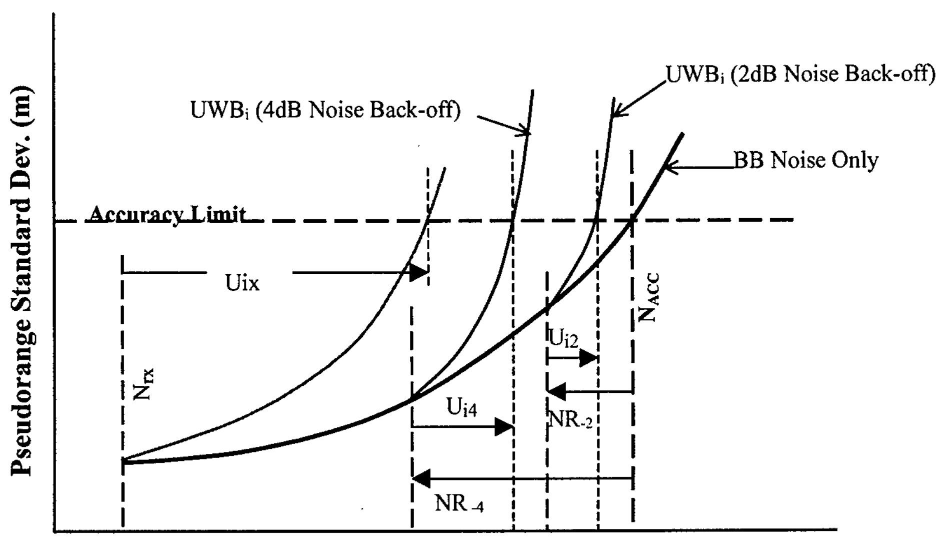


Figure 1. Graphical depiction of Interference Substitution Method for Pseudorange Standard deviation where Broadband Noise is the Standard Interference Signal.

5.0 SIMULATED SATELLITE CONSTELLATION

A multiple channel satellite simulator will be used in conducting all the GPS receiver tests. This provides a realistic test scenario as the effects on multiple PRN codes can be evaluated. The same satellite constellation scenario will be utilized for all of the tests.

For the PR tests, the satellite power into the receiver will be -151 dBW.

For the position accuracy and/or signal strength susceptibility tests, the satellite signal power will be adjusted such that the receiver C/N_0 is approximately 40 dB-Hz in the absence of any externally injected broadband noise or interference signals.

6.0 UWB WAVEFORMS

The UWB waveform parameters that will be used for the PLGR tests are as follows:

- 19.94 MHz uniform PRF
- 20.0 MHz uniform PRF
- 15.91 MHz nominal PRF, 2 position PPM dithered
- 1.994 MHz nominal PRF, 10 position PPM dithered
- Gold code modulated doublet, 57.08 kHz PRF
- OOK custom sequence, fixed 23 bit preamble followed by pseudorandom data stream of 4096 bits at 200 MHz

The testing of additional waveforms is optional.

7.0 TEST SET-UP

The standard test set-up is shown below (Figure 2). It is patterned after a similar one used in the previous Rockwell Collins UWB RFI tests on civil aviation GPS receivers done under FAA contract. The receiver Unit Under Test (UUT) is the PLGR. The RF signal generator is not used for the PR tests; however, the generator and the 10 dB coupler remain in the set-up in order to maintain consistent input noise levels. Detailed information on the calibration of the test set-up is provided in Attachment A of this appendix.

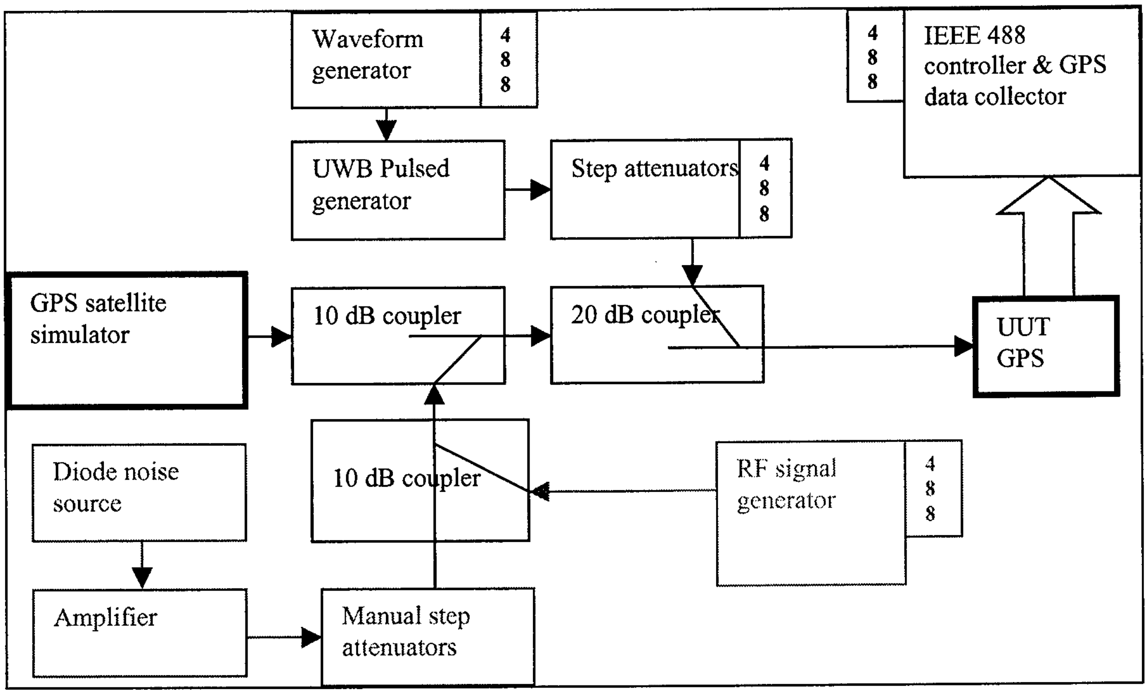


Figure 2. Test Set-Up

8.0 PLGR TEST 1 - PSEUDORANGE STD. DEV. TEST- P-CODE TRACKING

8.1 Objective and Rationale

The objective of this test is to determine the susceptibility of the pseudorange (PR) measurement standard deviation to UWB EMI for the PLGR when operating in P-code tracking mode. The unsmoothed pseudorange measurement is the performance metric of interest for this test. The standard interference type used for the interference substitution approach is broadband noise.

8.2 Test Set-Up

The test set-up diagram is shown in Figure 2. Broadband noise is used as the standard interference signal. The RF signal generator for CW interference is **not** used for this test.

8.3 Test Procedure for PLGR Test 1

The general test procedure for determining P-code PR measurement susceptibility is as follows:

1. **Initialize the PLGR operation**- Initiate satellite simulator scenario. Set the simulator signal level for -151 dBW at the receiver and have no added interference or broadband noise. Turn on, initialize, and command PLGR to Navigation mode. Allow the receiver to fully acquire satellites, obtain almanac information, and begin tracking a minimum of four satellites and achieve a steady-state tracking condition. To insure stable operating conditions, the PLGR should be powered up for at least 15 minutes before the following steps are conducted. Throughout the testing, the operator should frequently verify that the receiver is tracking and navigating properly. If not, the receiver should be reinitialized to the correct navigation state.

2. **Establish the performance baseline and threshold value:** This step establishes the pseudorange (unsmoothed) baseline performance threshold value for the standard RFI (broadband noise) level. Using a GPS input signal level of -151 dBW, add in the standard RFI and collect 5 minute intervals of PR and C/N_0 data (PLGR serial data Blocks 3 and 1283) at 5 levels about the standard RFI level of +22 dB Pd of noise power at the receiver input. The +22 dB Pd added noise power level is 6 dB above the equivalent background sky noise reference. The five different noise levels should be in 1 dB increments from 4 dB above sky noise to 8 dB above sky noise (+20 to +24 dB Pd) and will establish the noise performance baseline. The data should be post processed to determine the PR 1-sigma when the interference noise level is at +22 dB Pd. This PR 1-sigma is the performance threshold value. The +22 dB Pd noise level will be used as the standard RFI level for the subsequent data collection steps.

3. **Document PR threshold value:** Collect one five-minute interval of PR and C/N_0 data (Blocks 3 and 1283) with the standard RFI level of +22 dB Pd at the receiver input and the GPS signal at -151 dBW. Note the C/No.

4. **First reduced standard RFI test condition, 2 dB back-off:** Reduce standard interferer power 2 dB (first back-off level) from the standard RFI level and replace with UWB power until the PR performance threshold is achieved. Record the UWB power level that causes the threshold to be met. In practice, at least three UWB power levels each spaced by 3 dB attenuator steps may need to be tried to determine precisely where the threshold is achieved. The C/N_0 reading from the receiver is used to determine the likely UWB attenuator settings, since C/N_0 provides the best observable, though indirect, indication of PR measurement noise.

5. **Second reduced standard RFI test condition, 4 dB back-off:** Reduce standard interferer power 4 dB (second back-off level) from the standard RFI level and replace with UWB power until PR performance threshold is achieved. Record the UWB power level that causes the threshold to be met. In practice, at least three UWB power levels each spaced by 2 dB attenuator steps may need to be tried to determine precisely where the threshold is achieved. C/N_0 reading from the receiver is used to determine the likely UWB attenuator settings, since C/N_0

provides the best observable, though indirect, indication of PR measurement noise.

6. **Third reduced standard RFI test condition, No added RFI:** Remove all standard interferer power (third back-off level) and replace with UWB power until PR performance threshold is achieved. Record the UWB power level that causes the threshold to be met. In practice, at least three UWB power levels each spaced by 2 dB attenuator steps may need to be tried to determine precisely where the threshold is achieved. C/N_0 reading from the receiver is used to determine the likely UWB attenuator settings, since C/N_0 provides the best observable, though indirect, indication of PR measurement noise.

7. Repeat steps 3 through 6 for all of the candidate UWB waveforms.

8. Post-process the data to determine the UWB attenuator settings at which the PR performance threshold is achieved for each back-off level and for each UWB waveform. Standard RFI equivalency factors relative to the standard RFI for each UWB waveform can then be computed and documented.

Refer to Attachment A of this appendix for a more detailed description of the steps necessary to properly conduct the tests and record the data. Details of the post-processing steps are also provided in the attachment.

8.4 Test Output

The required results from this test consist of the following documentation. All of the input standard interferer power levels and resulting PR standard deviation values must be documented in order to verify that the receiver is functioning properly and to establish the baseline interference performance. Also, the UWB power level added for each of the three back-off levels must be recorded for every UWB waveform that was tested.

9.0 PLGR TEST 2 - P-CODE MODE - POSITION ERROR AND SIGNAL STRENGTH TEST

9.1 Objective and Rationale

The objective of this test is to determine the susceptibility of steady state P/Y-code tracking performance to UWB EMI for the PLGR. This test is motivated by the PLGR legacy susceptibility test. The legacy test is modified to follow the interference substitution method used for the other tests. The standard interference type used for the interference substitution approach is a CW signal at GPS L1 +0.4 MHz (1575.4 MHz + 0.4 MHz), with a fixed, specified level of intentional broadband noise jamming. The receiver will be commanded to the navigation mode and allowed to track in steady state for a specified period of time. Position error and C/N_0 levels are monitored in order to

determine the impact of the UWB EMI.

9.2 Test Set-Up

The test set-up diagram is shown in Figure 2. A CW signal from the RF signal generator is used as the standard interference signal. Intentional broadband noise jamming will also be present during the UWB susceptibility data collection runs.

The GPS signal from the simulator is adjusted so that the PLGR C/No is 40 dB-Hz with no added interference or added noise. This simulator signal level remains fixed through the balance of the testing.

The intentional broadband noise jamming is added in to the above GPS signal level until the C/No is reduced to 30 dB-Hz. This noise level remains fixed through the balance of the testing.

The CW signal at 1575.8 MHz (GPS L1 f_c 1575.4 MHz + 0.4 MHz offset) from the RF signal generator is added to the above determined GPS signal and added noise until the C/No is reduced to 28 dB-Hz. The CW level at the receiver input that produces the C/No of 28 is the standard RFI level for this test.

9.3 Test Procedure for PLGR Test 2

The general test procedure for determining P/Y-code steady state tracking susceptibility is as follows:

1. **Initialize the PLGR operation**- Initiate satellite simulator scenario. Set the simulator signal level for -151 dBW at the receiver and have no added interference or broadband noise. Turn on, initialize, and command PLGR to Navigation mode. Allow the receiver to fully acquire satellites, obtain almanac information, and begin tracking a minimum of four satellites and achieve a steady-state tracking condition. To insure stable operating conditions, the PLGR should be powered up for at least 15 minutes before the following steps are conducted. Throughout the testing, the operator should frequently verify that the receiver is tracking and navigating properly. If not, the receiver should be reinitialized to the correct navigation state.

2. **Establish the performance threshold value:** Establish and verify the position and signal strength baseline performance threshold of +/- 2 dB and/or 12 meters of horizontal/vertical position error for the standard RFI (CW tone) level. With a GPS signal level that produces a C/N_0 of 40 dB-Hz with no added noise, add sufficient broadband noise to reduce the C/N_0 to 30 dB-Hz. Then add in the standard CW interferer to reduce the C/No to 28 dB-Hz and collect 5 minutes of data for position and C/N_0 data (Block 3). This CW tone interference level causes

the signal strength deviation of - 2 dB. The CW level will be used as the standard RFI level for the subsequent data collection steps.

3. **Document performance threshold value:** To verify performance threshold, collect one five-minute interval of position and C/N_0 data (Block 3) with the GPS signal, added noise, and standard RFI level determined in Step 2.

4. **First reduced standard RFI test condition, 2 dB back-off:** Reduce standard interferer power 2 dB (first back-off level) from the standard RFI level and replace with UWB power until one or both of the signal strength and position error thresholds is achieved. Record the UWB power level that causes the threshold to be met. For this test, C/N_0 can be directly monitored in order to determine the UWB attenuator setting, position error can be checked in post-processing. Three 5 minute intervals of position and C/N_0 data for three different UWB attenuator settings near the threshold should be collected for post-processing in order to establish more accurate average estimates of the position error and signal strength deviation.

5. **Second reduced standard RFI test condition, 4 dB back-off:** Reduce standard interferer power 4 dB (second back-off level) from the standard RFI level and replace with UWB power until one or both of the position error and signal strength thresholds is achieved. Record the UWB power level that causes the threshold(s) to be met. C/N_0 can be directly monitored in order to determine the UWB attenuator setting, position error can be checked in post-processing. Three 5 minute intervals of position and C/N_0 data for three different UWB attenuator settings near the threshold should be collected for post-processing in order to establish more accurate average estimates of the position error and signal strength deviation.

6. **Third reduced standard RFI test condition, no added RFI:** Remove all standard interferer power (third back-off level) and replace with UWB power until one or both of the thresholds is achieved. Record the UWB power level that causes the threshold(s) to be met. C/N_0 can be directly monitored in order to determine the UWB attenuator setting, position error can be checked in post-processing. Three 5 minute intervals of position and C/N_0 data for three different UWB attenuator settings near the threshold should be collected for post-processing in order to establish more accurate average estimates of the position error and signal strength deviation.

7. Repeat steps 3 through 6 for all of the candidate UWB waveforms.

8. Post-process the data to determine the UWB attenuator settings at which one or both of the performance thresholds is achieved for each back-off level and each UWB waveform. Standard RFI equivalency factors relative to the standard RFI for each UWB waveform can then be computed and documented.

Refer to Attachment A of this appendix for a more detailed description of the steps necessary to properly conduct the tests and record the data. Details of the post-processing steps are also provided in the attachment.

9.4 Test Output

The required results from this test consist of the following documentation. All the input standard interferer power levels and resulting signal strength and position error values must be documented in order to verify that the receiver is functioning properly and to establish the baseline interference performance. Also, the UWB power level added for each of the three back-off levels must be recorded for every UWB waveform that was tested.

APPENDIX C
Attachment A

PLGR Detailed Test and Post-Processing Procedure

OVERVIEW

The unit under test is a Collins PLGR GPS receiver. The GPS signal source is a Collins PCSG satellite simulator. The GPS signal standard interference sources are broadband noise or a CW RF signal. An Ultra-wide Band generator from MSSI generates various UWB pulse trains whose interference effects on the PLGR are to be quantified.

1.0 TEST HARDWARE SETUP AND TEST EQUIPMENT

The following table lists the test equipment used for this procedure.

Name/description	Mfg/model	note
UWB generator	MSSI BFP1000	NETEX GFE
Step RF attenuators & controller	HP 11713A driver, 8494H & 8496H attenuators	DC-18GHz, 1 & 10 dB steps, HPIB controllable
Manual RF step attenuators	Agilent 8494A & 8496A	1 & 10 dB steps
Directional couplers	Narda 3042B-10	10 dB, .92 to 2.2 GHz
Directional coupler	Narda 3022	20 dB, 1-4 GHz
Noise diode	HP 346B	Min 14 dB ENR
Amplifier	Mini-Circuits ZEL-1217LN	1.2 to 1.7 GHz 20 dB gain, low noise amp
Arbitrary waveform generator	TEK AWG2021-02	Dual channel with defined waveforms
GPS simulator	PCSG	Scenario- 6 satellite static
Signal generator	HP8648D	9KHz to 4 MHz range
Computer	With PLGR data logging software and serial port	For PLGR data logging
IEEE 488 bus controller	TE controller computer with HPIB interface	Custom LabView programs
DC power supplies	as needed	For noise diode and amp
PLGR Preamp Module	988-4220-001	For use with PLGR Aux antenna port input
PLGR Power Adapter	AC to DC converter	To replace PLGR battery power

The equipment is set up as shown in Figure 1. The throughput loss for the signal paths are determined and recorded. These paths are from the UWB output coax connection to

the PLGR preamp input connector, from the GPS simulator connection to the PLGR preamp input connector, and from the CW Signal generator output connector to the PLGR preamp input connector.

The noise path is calibrated in measured noise power presented at the PLGR preamp input connector. The noise power levels for the various attenuation settings are recorded.

The UWB output power is measured at its output connector. A bandwidth limited power out is measured with a power meter and recorded for each individual trigger waveform to be used during testing. The UWB measurement filter has an 80 MHz bandwidth and a center frequency at GPS L1, 1575.4 MHz. The bandwidth limiting is removed for test.

The PCSG controllable satellite power levels are calibrated to the end of the PCSG coax.

The recorded CW signal level is the output of the calibrated signal generator.

All of the variable attenuators are calibrated for the appropriate frequencies they control.

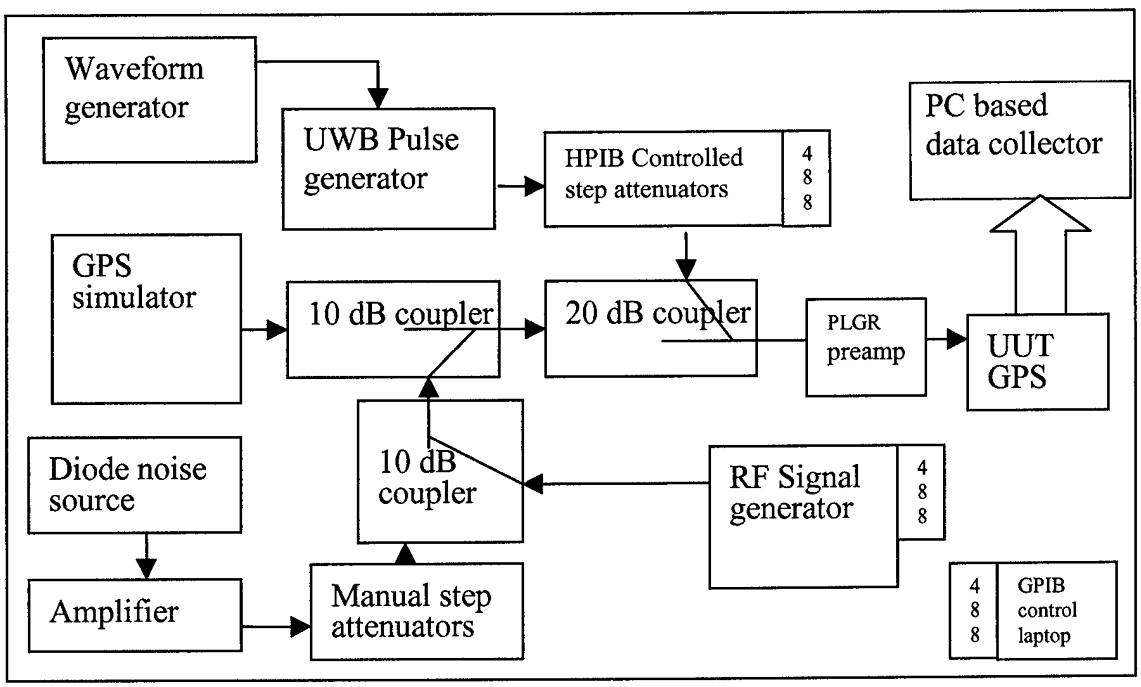


Figure 1. Test Set-Up

2.0 OPERATIONAL INFORMATION FOR PLGR GPS RECEIVER

****** To prevent the PLGR from automatically powering itself off every 15 minutes to conserve battery power- Set the AUTO TIME OUT function in the power menu to OFF.*****

PLGR has an integral antenna. The PLGR Aux RF Input is assumed to be for use with an active antenna and has +12V DC power on the RF Connection. The Aux RF input also bypasses the PLGR internal first low noise amplifier stage. The external PLGR Preamp Module contains a duplicate of the internal LNA, uses the DC power from the PLGR Aux port, and provides DC isolation for the Preamp RF Input. The Preamp Module is a Controlled Rockwell Assembly CPN 988-4220-001 Rev A. For the February 2003 testing, the Preamp Module was manufacturing control number MCN-187.

The PLGR is connected to a PC data logger via a serial data bus. The PLGR data logging software is KLUDGE, a Rockwell loosely controlled custom application. The serial data Blocks containing the necessary data for analysis are 3 and 1283. These message blocks must be "connected" (included in the serial output stream) prior to data collection.

The collected KLUDGE data is converted to a Mission Planning Software (MPS) compatible format using the KLG2MPS custom software utility. MPS is a more rigorously controlled Rockwell software suite that can sort and extract the PLGR serial data elements.

The PLGR power can be provided by an AC to 12V DC converter module.

To acquire a valid position fix and track satellites, the GPS requires almanac information. Almanac can be acquired during the first 15 minutes of a scenario via information from the satellites. If the PLGR is not powered down, it will retain the almanac data for a particular simulation scenario.

In addition to almanac, the PLGR requires the initialization of the position, date, and time to be hand loaded. The initialization time and position are determined by the GPS simulator scenario used. After the PLGR is powered up and has passed self test, enter the time and position relatively close to that of the start of the scenario simulated time and scenario position.

To initialize, go to the PLGR STDBY mode, then INIT Date, Time and Pos, then return the mode to CONT. The KLUDGE program can change the mode, but the initialization information must be entered with the PLGR buttons.

The PLGR NAV performance is monitored via displays available in the STAT menu.

The summary PLGR initialization sequence is:

1. Power on, and allow automatic self test to complete,
2. Go to STDBY mode, manually enter initial time, date and position information,
3. Return to CONT mode

3.0 OPERATIONAL INFORMATION FOR PCSG GPS SATELLITE SIMULATOR

The PCSG is the GPS satellite constellation simulator. It is controlled with computer based command files. The satellite information is provided by a software satellite "scenario" file stored on the computer and called up by the command file.

The PCSG is controllable by a defined set of commands. The command menu is not detailed as it is specified elsewhere and applicable only to this simulator. The commands are used to define the initial operating conditions at the start of a scenario run. They are also used to allow interactive changes to be made to the PCSG output characteristics while a scenario is running.

The individual command lines can be used to created command files. In the command files, the lines can be executed immediately when read, or at either a specified GPS scenario time or at some real time delay after the line has been read. The commands can control the output power of the individual satellite channels, turn the P/CA codes or L1/L2 frequencies on and off, as well as many other functions.

The following anomalies apply only to the PCSG simulator. The satellite output power is only calibrated if the master satellite control attenuator is set to 0. Each satellite's power must be individually commanded to a specified level. The command to "change all" satellite channel powers at the same time does not produce a calibrated output level. Again for the PCSG only, even with the calibrated output levels, for a defined level, the actual channel powers can be mismatched by as much as 1 dB. The satellite power command sets both the L1 P code power and the L1 CA code power to the same level.

Associated with each satellite scenario is an almanac of information that the GPS receiver uses to know which satellites are available to track. In a normal situation, almanac is downloaded from the satellites to the GPS and can take up to 15 minutes. For a given scenario, the downloaded almanac will then be valid until the PLGR is powered down.

For this testing, we have generated a custom scenario that has 6 visible satellites and the GPS is stationary. The scenario name is MG1005Y.idf. It has a fixed position of approximately N 033 and W114, a date of December 25, 1983 (year 83, day 359), and a scenario start time of approximately 16:50 UTC.

The PCSG computer is controlled by the control command file.

The desired PLGR information must be inserted in the serial output data stream using KLUDGE. For this test procedure, the serial data Blocks 3 and 1283 must be "connected" prior to data collection.

The Data logging computer records the PLGR serial data as directly by the KLUDGE software for specified periods of time. KLUDGE will ask for a data file name for each run (*.log).

The KLUDGE *.log file is converted to a Mission Planning Software (MPS) compatible format with the KLG2MPS utility. The MPS software can be used to extract the Block 3 and Block 1283 data into *.csv formatted text files.

4.0 OPERATIONAL INFORMATION FOR THE ULTRA WIDEBAND GENERATOR

The Ultra Wideband generator (UWB) was supplied by MSSI. Although the generator has the capability to internally generate various waveforms and control the UWB power level; for this testing, we supply these functions externally. The UWB pulse waveforms are triggered by signals from an arbitrary waveform generator. The UWB power is varied by using HPIB controlled step attenuators.

The various waveforms used to trigger the UWB were generated by an arbitrary waveform generator (AWG). The waveforms were defined and permanent AWG compatible files were generated and saved to enable consistent rerunning of the waveforms. The TEK2021 AWG loses all loaded waveform data when powered down.

To produce AWG waveforms, the complex trigger data string sequences were generated in Mathcad or Excel and stored in comma separated variable text files. These text files were converted to AWG usable files using a csv2wfm.exe file obtained from the Tektronix website. An idiosyncrasy of the TEK2021 AWG is that the data file lengths must be divisible by 8.

The UWB generator requires the AWG output level to be at a magnitude of at least 4.2 Volts and a DC offset of 1 Volt. The UWB output pulse shape and power level were sensitive to AWG drive level. Even with the same drive levels, the trigger would produce different power out and RF pulse characteristics when it was switched between the positive and negative trigger inputs. All of the UWB power measurements used the same 4.2 VDC trigger magnitude and 1.0 VDC offset.

The UWB power levels are individually determined for each waveform. The bandwidth limited power is measured at the UWB output.

The UWB had a time skew between the positive and negative trigger input responses. This skew was offset by varying the cable length between the AWG channel outputs and the UWB trigger inputs. These cable lengths became part of the calibrated setup.

The UWB power to the PLGR was adjusted by a calibrated set of HPIB controllable step attenuators. An automated LabView program controlled the attenuators during data collection recordings. The program allowed the UWB level control attenuators to dwell at defined attenuation levels for a fixed amount of time.

5.0 OPERATIONAL INFORMATION FOR REFERENCE INTERFERENCE SOURCES

5.1 Broadband noise

The broadband noise interference signal is generated by a noise diode with the noise output amplified by a low noise amplifier. The noise level presented to the PLGR is controlled by manually adjusted step attenuators. The level is calibrated at the input connector of the PLGR.

Due to the amplifier in the noise string, when a data collection set requires no added noise, the DC power is turned off to both the noise diode and the amplifier. Even with no input signal, the amplifier could generate a small amount of noise that might influence the data.

For our tests, a reference noise power level of 16 dB Pd is referred to. This noise power level is representative of typical sky noise projected through an ARINC 743 active antenna GPS input configuration. The ARINC 743 configuration assumes 13 dB of cable loss and an input amplifier with 26.5 dB of gain and with a noise figure of 4 dB. This level was arbitrarily chosen for this testing to allow some consistent reference for both commercial and military GPS units.

5.2 CW RF signal

The CW signal used for some testing is generated by an Agilent RF Signal Generator. The CW levels referred to during test are the output levels of the signal generator. The generator control is integrated into our LabView HPIB controller program.

The custom LabView program can control the levels of both the UWB and the CW signal.

6.0 DATA COLLECTION

PLGR data blocks 3 and 1331 must be included in the output serial data stream by use of a KLUDGE connect function.

The PLGR data collection is recorded with GPS time tags. This GPS time is the time the scenario is presenting to the GPS. This GPS time is not actual time nor run time. The GPS time will repeat every time a scenario is restarted.

KLUDGE records the PLGR serial output data into a *.log file. KLG2MSP converts the PLGR serial data to MPS formatted serial data (MPS.log). The Block 3 and Block 1283

data is extracted into comma separated variable formatted text files (*.csv) with the MPS software.

7.0 INDIVIDUAL TEST PROCEDURES

The test sequences will be defined in the following sections. Initially for all tests, the GPS signal level will be set to -150 dBW, the interference noise will be off, and the CW interference will be less than -100 dBm.

7.1 P-code Pseudorange Test with Noise as STD RFI

7.1.1 Initialization

1. Set the PCSG command file to output individual satellite power levels so that -151 dBW is presented at the PLGR Preamp input.
2. Start the PCSG scenario with command file.
3. Initialize PLGR by manually loading position, time and date while in STDBY mode.
4. Set PLGR to CONT mode.
5. Allow download of the almanac information if necessary. This can take up to 15 minutes.
6. Allow PLGR to acquire solid tracking on at least four satellites.
7. Add noise at a level of +22 Pd dB at the PLGR Preamp input.

7.1.2 Collection of UWB interference data

1. For threshold confirmation and approximate C/No at threshold, collect serial data for a five minute interval with -151 dBW GPS signal and +22 dB Pd added noise. Record simulator scenario GPS time at start and end of timed run for use later in data post-processing. Make a note of the C/No.
2. Before the start of data collection, the approximate UWB levels need to be determined. The added noise will be reduced 2 dB and 4 dB below threshold (+20 and +18 dB Pd), and then turned off. These are the three noise back-off levels. At each back-off level, the UWB interferer will be added in until the Step 1 determined C/No is reached. The UWB level is noted. The UWB power is then varied until the Step 1 C/No changes +1 dB, and then -1 dB. Post processing works more easily if the UWB dB step changes are equal. The UWB levels necessary to produce the plus and minus 1 dB changes are noted. Repeat for the 4 dB back-off and the no added noise cases. The 2 dB noise back-off level should have least 3 dB step changes in UWB interference power. For the 4 dB back-off and no added noise back-off level, the UWB attenuator step changes should be at least 2 dB apart.
3. Load the UWB attenuator settings from above into LabView control program. This program will change the UWB attenuator setting every 5 minutes. The noise attenuator will be manually changed for each noise back-off level.
4. Start PLGR data recording for a minimum of 50 minutes. Manually set the added noise to 2 dB back-off (+20 dB Pd). Start the LabView program and record start

time in GPS scenario time. At start time plus 15 minutes, manually reduce added noise to 4 dB back-off level (+18 dB Pd). At start time plus 30 minutes, turn off DC power to noise source and noise amplifier. At start time plus 45 minutes, data collection sequence in completed. Record GPS time at the start and the end for use in data processing. Record the attenuation settings. Allow PLGR data recording to time out.

5. To verify that the threshold performance has not changed during the run, set added noise to threshold value, +22 dB Pd, and remove all UWB signal by setting attenuators to maximum attenuation. Collect data for 5 minutes. Record GPS start and stop times.
6. Terminate the PCSG scenario run.
7. Record the file names and the associated data collection run conditions, GPS times, attenuator settings, etc. Copy files onto transferable media for data processing.

7.2 Position and Signal Strength Test with CW as STD RFI and Fixed Added Noise

7.2.1 Initialization

1. Set the PCSG command file to output individual satellite power levels so that -151 dBW is presented at the PLGR Preamp input.
2. Start the PCSG scenario with command file.
3. Initialize PLGR by manually loading position, time and date while in STDBY mode.
4. Set PLGR to CONT mode.
5. Allow download of the almanac information if necessary. This can take up to 15 minutes.
6. Allow PLGR to acquire solid tracking on at least four satellites.

7.2.2 Determine Standard RFI

1. With no added noise or interference signals, adjust satellite signal levels to produce C/No value of 40 dB-Hz (approximately -160 dBW). Record satellite power level.
2. Add broadband noise at a level to reduce C/No value to 30 dB-Hz. Record noise level.
3. Add CW interferer signal at 1575.8 MHz (L1 + 0.4 MHz) at a signal level high enough to change the C/No 2 dB or the position 12 meters. Record the CW signal level. This is the STD RFI. In all of our cases, the C/No decreased to 28 dB. The 28 dB C/No is the performance threshold value.

7.2.3 Collection of UWB interference data

1. Collect a five minute interval of data at the GPS signal and interferer levels (noise and STD RFI) described above in Section 7.2.1 and 7.2.2. Record GPS time at start and end of timed run for use later in data processing.
2. Before the start of data collection, the approximate UWB levels need to be determined. The STD RFI level will be reduced 2 dB and 4 dB, and then turned

off. These are the three back-off levels. With the CW is set to 2 dB below the STD RFI power, the UWB interference is added in until PLGR C/No equals 28. The UWB level is noted. The UWB power is then varied until the C/No equals 27 and then C/No equals 29. The necessary UWB power levels are noted. To ease post processing, the UWB dB step changes are equal. Repeat for the 4 dB back-off and the no added noise cases. The 2 dB noise back-off level should have least 3 dB step changes in UWB interference power. For the 4 dB back-off and no added noise back-off level, the UWB attenuator step changes should be at least 2 dB apart.

3. Load the CW levels for Backoff conditions and the UWB attenuator settings from above into the LabView control program. This program will change the UWB attenuator setting every 5 minutes and the CW level every 15 minutes. The noise is constant throughout the run.
4. Start PLGR data recording for a minimum of 50 minutes. Start the LabView program and record start time in GPS scenario time. At start time plus 45 minutes, data collection sequence in completed. Record GPS time at the start and the end for use in data processing. Record the CW levels and UWB attenuation settings.
5. To verify that the threshold performance has not changed during the run, turn off the UWB (max attenuation). Collect five minutes of data at the GPS signal and interferer levels (noise and STD RFI) described above in Section 7.2.1 and 7.2.2. Record GPS time at start and end of timed run for use later in data processing.
6. Terminate the PCSG scenario run.
7. Record the file names and the associated data collection run conditions, GPS times, attenuator settings, etc. Copy files onto transferable media for data processing.

8.0 POST-PROCESSING PROCEDURE

The following steps describe how to post-process the raw message block data collected during the tests in order to compute the performance metric levels for each of the back-off levels and each of the UWB attenuator settings. The appropriate raw message data must first be extracted using one (or two) DOS utilities and then subsequently processed in Matlab (or equivalent) in order to compute the performance values of interest. Once the performance metric data are computed and recorded with the associated levels of UWB interference used during the test, standard RFI equivalence factors can be computed.

8.1 Data Extraction and Performance Metric Computation

1. Use KLG2MSP to convert the PLGR serial data to MPS formatted serial data (MPS.log).

2. Use MPS software to extract Block 3 and Block 1283 data into comma separated variable formatted text files (*.csv).

3. Process data with Matlab or equivalent as described below for each type of test.

For PR noise tests:

1. Extract PR, DR and C/N_0 data from message Blocks 3 and 1283 for all the PLGR channels
2. Read in to Matlab (Delete column headings from output file first.)
3. For each PRN do the following
    i. Filter out the correct PR and DR data
    ii. Filter out the correct C/N_0 data
    iii. Retain only valid PR (PR Validity bit = 1) and valid DR (DR Validity flag = 31) data
    iv. Convert PR to units of meters by multiplying raw data by 29.305/1023, and convert DR data to units of meters/sec by multiplying by 29.305/1023/19.25.
    v. Integrate DR data to compute Integrated DR. (Generates a pseudo carrier phase measurement in order to compute single difference residual. Also, for each second one needs to sum the five 0.2 sec raw DR measurements to create the full 1 second DR measurement before integration is performed.)
    vi. Compute difference between PR and Integrated DR residual
    vii. Detrend residual (Since the PLGR does not output a true continuous carrier phase measurement, the Integrated DR serves as the closest proxy to carrier phase. However, the Integrated DR has a slight, but constant, drift relative to the PR measurement. The detrending operation has an insignificant effect on the PR noise variance.)
    viii. Select the intervals based on recorded GPS time where detrended is valid and PR 1-sigma noise should be computed. Plot data and inspect to insure that no discontinuities or obvious glitches are apparent over the interval.
    ix. Compute 1-sigma values of PR noise for the selected intervals and record computed values with the associated UWB attenuator setting.
    x. Compute and record the average C/N_0 for the same interval

For the Position/Signal Strength test:

1. Extract the position and C/N_0 data from message Block 3
2. Read in to Matlab (Delete column headings of output file first.)
3. Retain only the valid data (TFOM < 4 and FOM = 1)
4. Over all the UWB attenuation setting intervals
    i. Compute the horizontal and vertical position errors over the interval
    ii. Compute the average C/N_0 over the interval
    iii. Record computed values with the associated UWB attenuator setting.

8.2 Standard RFI Equivalence Factor Computation

Given the computation of the performance metric values from the recorded raw data as described in the previous section, it is necessary to determine the UWB power levels at which the metric's accuracy limit is achieved for each of the back-off levels. The test

procedures designed such that accuracy limit will likely fall in the range of the values that are computed from the recorded data. However, this will not always occur. For example, the PR noise is directly observable during the data collection of the PR noise tests, so UWB attenuator settings must be estimated from C/N_0 readings. When the accuracy limit does not fall into the range of the post-processed performance metric values, then the UWB setting can be determined by extrapolating the computed metric values. In extreme cases where extrapolation of the computed metric values would be highly inaccurate, then additional data would need to be collected to estimate the UWB power level at which the accuracy limit is achieved.

Given the UWB attenuator settings, and hence, the UWB power values, at which the accuracy limit is achieved for each back-off level, it is then possible to compute the standard RFI equivalency factor for each waveform evaluated for each of the five tests. This computation is illustrated in Figure 2. The log of the slope is the waveform specific RFI equivalency factor (in dB) that can be used in RFI link budget analysis. Note that since three back-off levels are determined for each test and each waveform, it is possible to compute three different equivalency factors for each waveform in each test. Computing multiple equivalency factors can indicate whether the impact of UWB interference is linear or non-linear as a function of power.

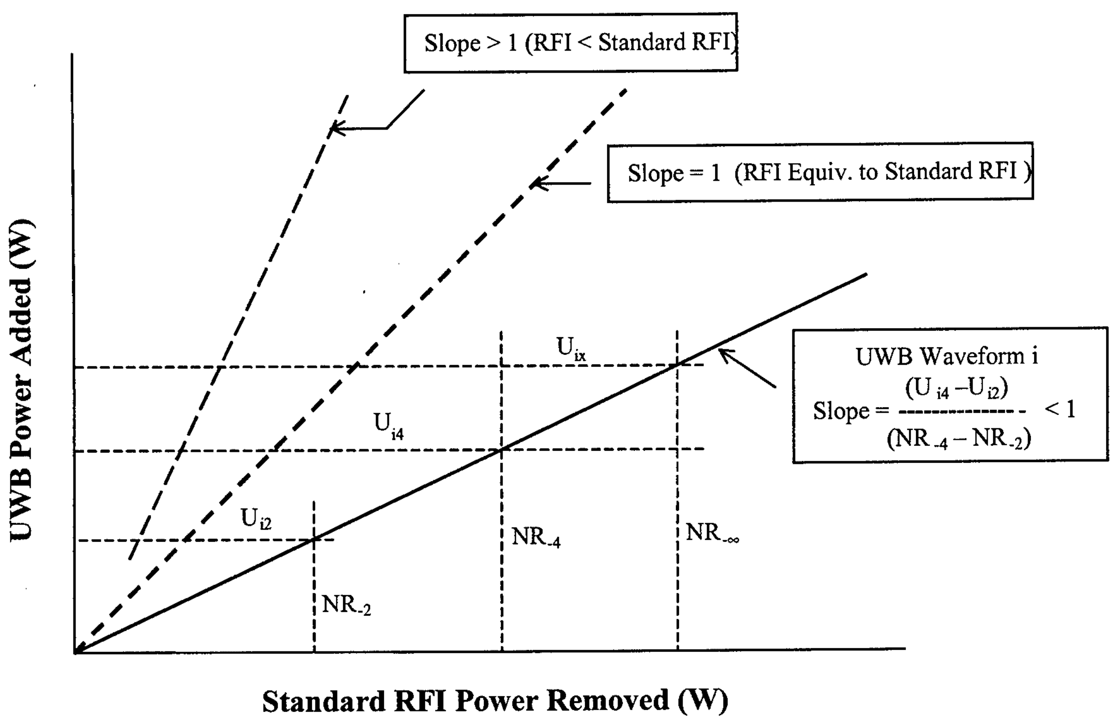


Figure 2. Standard RFI Equivalency Factor Graphical Description

Sample Data Sheet

Filename/Test ID________________________
Data for:

_________ Pseudorange variance test
_________ Position signal strength test

Date__________________
Technician _____________

PLGR S/N ______
Document and attach complete test equipment list

Calibration adjustments
Simulator output to PLGR input path loss =________dB
CW signal output to PLGR input path loss =_________dB
UWB output to PLGR input path loss =_________ dB
Noise power at PLGR input is +16 dB Pd with noise path attenuator set to ____dB

Satellite simulator scenario
Name _________________
Initial scenario position LAT_______ LONG________
Initial scenario time YEAR_________ DAY________ TIME_______

UWB modulation waveform ____________________________________
AWG waveform filename ____________________________________.wfm
AWG adjustments (if any):

AMPL _________V, OFFSET ___________V
CLOCK__________MHz

Start simulation scenario. Initialize PLGR with above time, date and position. Allow time for PLGR to achieve satellite tracking.

Determine correct normal operating conditions and set levels as defined by the test:
Record satellite signal level _____________dBW
Record noise path attenuator setting _____________________dB
Record CW setting (if used) _________________dBm

Baseline data
Noise level attenuator settings ________________dB
for 5 or ______ minutes
Data collection start time ____________
Data stop time______________

UWB step data:

Labview program start time________________

Each program step is 5 or _____ minutes
UWB attenuation is added to UWB path loss

Control program step number	UWB attenuator setting	CW level @ signal generator (dBm)	Noise attenuator setting
1			
2			
3			
4			
5			
6			
7			
8			
9			

Labview program end time ________________-

UWB off, baseline conditions, 5 minutes minimum

Data start time_____________
Settings:
Simulator _______________dBW
Noise attenuator ___________dB
Data end time______________